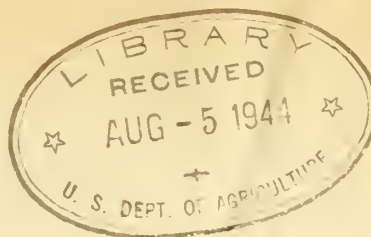


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ACE-142
Part II

THE CHEMISTRY AND TECHNOLOGY OF THE SOYBEAN
AND ITS DERIVED PRODUCTS

By

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Urbana, Illinois

Part II

Processing of Soybeans and Soybean Products

By Warren H. Goss

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CONTENTS

	Page
Processing soybeans	2
Development of the soybean processing industry.	2
Grading and storage.	5
Methods of processing soybeans	7
Processing by means of continuous presses.	9
Processing by means of continuous solvent extractors	15
Hydraulic pressing	26
Miscellaneous processing methods	29
Soy flour.	30
Cost of processing soybeans	30
✓ Production and refining of phosphatides	35
✓ Processing soybean oil for food uses.	38
Neutralization and washing	38
Bleaching.	41
Hydrogenation.	42
Deodorization.	46
Winterizing.	47
Shortening	48
Margarine.	50
Literature cited.	52

Processing Soybeans

1. Development of the soybean processing industry

The processing of soybeans to produce oil and meal is a very old industry in the Orient (12), ^{3/}where rather primitive equipment is still widely used. In the United States the soybean processing industry is a comparatively new one, having been developed almost entirely within the past 20 or 25 years. Soybeans have been grown more or less experimentally in various sections of the country for over a hundred years, and it is therefore possible that some of the cottonseed oil mills in the southern or southeastern part of the country crushed small amounts of soybeans earlier than those operations which have been recorded.

The first soybean crushing in the United States for which records are available ^{4/}, however, appear to have been on Manchurian beans in about 1911. The soybeans were imported by the Albers Brothers Milling Company and sold to a Mr. Herman Mey, who operated a small hydraulic press oil mill in Seattle, Washington. The establishment was later known as the Pacific Oil Mills, but it is no longer in existence. The meal produced in these operations was sold as a feed ingredient under the name of "Proteina." It was found, however, that the oil and meal could be imported more cheaply than they could be domestically produced from imported raw materials, and the crushing operations were therefore discontinued when the initial shipment of beans had been processed.

The earliest recorded crushing of American-grown soybeans ^{5/} took place at the cottonseed oil mill of the Elizabeth City Oil and Fertilizer Company in Elizabeth City, North Carolina. This mill was later operated by the Eastern Cotton Oil Company, but its operations were discontinued in the early 1930's. The first soybean crush was largely a test run extending from December 13 to 20, 1915. During that time, 10,000 bushels of local soybeans were pressed in the 6 expellers with which the mill was equipped, and the resulting meal was reported to be of excellent quality, containing 5.0 to 5.5 percent oil. The test was conducted by Mr. W. T. Culpeper, manager of the firm, as part of his activities toward encouraging local soybean production. The experiment was so successful that the company continued to process local soybeans, as supplies became available, and they reportedly offered production contracts with the farmers in advance in order to induce farmers to grow more of this crop. In spite of their efforts to develop the production of soybeans sufficiently to assure regular operations, difficulties were encountered from time to time in obtaining enough beans to warrant crushing them. In 1916, for example, it is said that German interests bought and exported the entire available supply at prices as high as \$4.50 per bushel.

^{3/} Numbers in parentheses refer to Literature Cited.

^{4/} Eilertsen, L. W. Personal communication.

^{5/} Morse, W. J. Personal communication.

In late 1917 or early 1918, the Chicago Heights Oil Manufacturing Company 6/ experimentally processed a small amount of soybeans in expellers which were originally designed for crushing corn germs. During 1918, this company is said to have added two expellers specifically for crushing soybeans. These expellers had a combined capacity of 600 bushels per day and were used intermittently during the ensuing years as supplies of beans became available. In the fall of 1922, the same company is said to have experimented with hydraulic press equipment which had been used for producing linseed oil. The Chicago Heights Oil Manufacturing Company continued its pioneering efforts toward the establishment of a soybean industry in the present "soybean belt" until August of 1923 when it went out of business. The equipment was purchased by Funk Brothers Seed Company of Bloomington, Illinois, during the following year, and the latter company has since been continuously engaged in the soybean processing business.

On September 30, 1922, the A. E. Staley Manufacturing Company (183) of Decatur, Illinois, commenced operations in a mill which was equipped with expellers designed for crushing soybeans. This company has been in the soybean processing business continuously since that date. The Staley development was soon followed by others of a similar nature, and the early twenties saw the establishment of a permanent soybean processing industry.

Not all the earlier ventures proved successful. For example, the Piatt County Soybean Cooperative Company (sometimes referred to as the Monticello Grain Company) was organized in 1922 in Monticello, Illinois, and installed batch solvent extraction equipment for processing 300 bushels of soybeans per day (6). The solvent used is said to have been benzol. This ill-fated undertaking was apparently unable to cope with the scarcity of beans and was in operation for only about 6 months during the period 1923-1924.

Another early attempt at solvent extraction of soybeans was undertaken during the years of 1924 and 1925 by the Eastern Cotton Oil Company at Norfolk, Virginia 7/. A Pollmar type of continuous extractor having a capacity of approximately 80 tons per day was used on soybeans obtained from North Carolina, but the supply proved to be inadequate. Difficulty was also encountered in adapting the German-manufactured equipment to the processing of American-grown soybeans. After exhausting the available stocks of soybeans, the mill's operations were transferred to the extraction of Argentine flaxseed, but this was said to have been found unprofitable.

At about the same time, soybeans were solvent-extracted by the Prossco Oil Company, also in Norfolk, using Scott rotary extractors. Their operations, however, consisted mainly in the extraction of cocoa butter and other fats, and only a small amount of soybeans is said to have been processed. Others who engaged in soybean processing during the early twenties include the Seeds Oil Company in Indianapolis and the Jonathan Havens Oil Company at Washington, North Carolina.

6/ Schinke, Carl H. Personal communication.

7/ Schwartz, A. K. Personal communication.

The foregoing instances are but a few of the many examples of the pioneer effort carried out by those who possessed the courage and foresight to enter what was then an unknown and untried field. These efforts, however, were the outgrowth of and were made possible by still earlier pioneering along agronomic and educational lines. It is a well-recognized fact that the one development which made possible the founding of a soybean industry in the present "soybean belt" was the introduction of varieties adapted to the soil and climate of the region. The present status of the soybean as a major crop is a tribute to the early research performed by the U. S. Department of Agriculture and the Agricultural Experiment Stations. No less credit is due the small group of farmers who cooperated by taking up soybean cultivation according to the practices recommended by the agronomists (145).

The early processors were faced with the task of developing markets for their hitherto untried products. Initially, little was known concerning the value of soybean oil meal for feeding purposes. Stock feeders were persuaded to accept free batches of meal for feeding trials. Meal was sent to various state experiment stations and exhibited at state fairs, county fairs, etc. By the end of the 1920's, these and other educational efforts had borne fruit and soybean oil meal had established itself as a valuable protein supplement in the feed industry.

Similarly, the first domestically produced soybean oil found an unreceptive market. It was not known that soybean oil could be refined, bleached, and deodorized to produce a high grade edible product, and its value in the drying oil industry was equally uncertain. Prospective buyers could cite dozens of reasons why soybean oil was not satisfactory, and it remained for the more farsighted oil processors and buyers to demonstrate to the prospective consumers that soybean oil could be used in both the edible and drying fields.

A large number of growers of soybeans and other individuals interested in the industry are organized in the American Soybean Association. This organization has played a prominent part in the development of the American soybean industry and was founded in 1920 under the name of "The National Soybean Growers' Association" (1, 3, 4). The association adopted its present name in 1925.

In more recent years there has been organized a group of soybean processors known as the "National Soybean Processors' Association." It was organized in 1930 and its original membership (7) was quite representative of those soybean processors who pioneered their industry.

At the present time, soybean oil and soybean oil meal are handled by processors, brokers, and others, in all parts of the country. Soybeans can be bought and sold for future delivery on the Chicago Board of Trade, meal futures are handled by the Memphis Merchants Exchange, and trading in soybean oil futures is carried on by the New York Produce Exchange. For a more detailed description of the present economic position of the soybean processing industry, the reader is referred to references Nos. 51, 55, 60, 62, 76, 86, 109, 128, 184, and 197, in the bibliography.

Soybeans are processed in large quantities in the Orient, Europe, and the United States, and it is therefore to be expected that processing practices would differ considerably from one country to another. Not only do processing practices vary from country to country; but in the United States at least considerable variations are encountered throughout the industry, no two plants being exactly the same. In Europe and the United States, the industry is highly mechanized. This is also the case in the Orient in the large oil centers at Dairen, Kobe, and Newchang. However, many primitive mills still continue to operate in districts away from the main centers of production. Although American methods of processing prior to actual removal of the oil vary from mill to mill, nevertheless certain operations such as storage and cleaning are more or less common to the industry as a whole.

2. Grading and storage

Until comparatively recently, Government inspection and grading of soybeans was on a purely voluntary basis and was administered by the Inspection Service of the Grain and Seed Division of the Agricultural Marketing Service (formerly of the Bureau of Agricultural Economics) in accordance with the standards promulgated by the Bureau of Agricultural Economics (196). The activities of the Inspection Service ordinarily cover such commodities as hay, straw, beans, peas, various seeds, etc. Effective November 20, 1940, an amendment to the United States Grain Standards Act provided for the inspection and grading of soybeans under the Administration of the Grain Standards Act as carried out by the Grain and Seed Division (194). This amendment has had the effect of putting soybean inspection on the same basis as that of other grains such as wheat, corn, oats, barley, rye, and flaxseed, and it makes mandatory the use of the standards when grain is sold by grade in interstate or foreign commerce.

Present standards (195) designate 5 classes of soybeans: Class I, yellow; Class II, green; Class III, brown; Class IV, black; and Class V, mixed. In addition, soybeans are classified, according to their physical condition, into any one of 5 grades, as shown in Table 1. (See Table 1 on Page 6)

In determining grade, a single factor is sufficient to throw soybeans of one grade into a lower grade. For example, a lot which grades No. 2 yellow in all respects except that its moisture content is 16 percent would be graded as No. 3 yellow. It is often possible to mix two batches, one or both of which would alone receive a lower grade, in order to produce a blended lot that will meet the requirements of a higher grade (17).

Soybeans are received at elevators by rail, truck, or boat. They are unloaded from cars and ships by means of automatic shovels, air hoses, or, in many large rail terminals, by automatic car unloaders. They must first be cleaned by running them through magnetic separators to remove tramp iron and through screening devices which remove stones, weed seeds, and other foreign material likely to cause heating in storage. If the moisture content is below 13 or 14 percent, the beans can be run directly to the storage bins; otherwise they must be dried to reduce the danger of heating.

Table 1. Grade Requirements for Yellow Soybeans, Green Soybeans, Brown Soybeans, Black Soybeans, and Mixed Soybeans

Grade No.	Minimum test weight per bushel	Maximum limits of -			
		Mois- ture	Splits	Damaged kernels (soybeans and other grains)	Foreign material other than dockage
	Pounds	Percent	Percent	Percent	Percent
1 <u>1</u> /-----	56	13	10	2	1
2 <u>1</u> /-----	54	14	15	3	2
3 -----	52	16	20	5	3
4 <u>2</u> /-----	49	18	30	8	5

Sample grade - Sample grade shall include soybeans of any of the classes Yellow Soybeans, Green Soybeans, Brown Soybeans, Black Soybeans, or Mixed Soybeans, which do not come within the requirements of any of the grades from No. 1 to No. 4, inclusive; or which contain stones and/or cinders; or which are musty, or sour, or heating, or hot; or which have any commercially objectionable foreign odor; or which are otherwise of distinctly low quality.

1/ The soybeans in Grade No. 1 of each of the classes Yellow Soybeans and Green Soybeans may contain not more than 2 percent, and the soybeans in Grade No. 2 of each of these classes may contain not more than 3 percent of Black, Brown, or bi-colored soybeans, singly or combined.

2/ Soybeans that are badly weathered or badly stained shall not be graded higher than No. 4

* * * * *

Storing of soybeans resembles that of most of the other grains and presents no great technical difficulty (2,5,8,9,10,18,140,198). Although 13 percent moisture is the generally accepted maximum, it is quite possible to store the beans at moisture contents as high as 16 percent, or sometimes slightly higher, for short periods if they are carefully watched and turned at the first evidence of heating. This is not the usual practice, and beans containing over 13 percent will very likely heat during the "sweat" which occurs in the spring (11). It is believed by many operators (199, 200) that if heating takes place in a small pocket of damp beans surrounded by dry beans,

it will spread to the dry beans, but some elevator operators contend that this does not occur appreciably with soybeans.

For removing moisture from whole soybeans, the usual types of grain driers are satisfactory. The beans pass downward over a series of baffles counter-currently to an upward blast of hot air. In some driers, the air is heated indirectly while others utilize the flue gases from a burner. Although practice varies considerably, the temperature of the air entering a typical drying unit is approximately 200° to 220°F. and the beans leave at a temperature of 180° to 200° F. Higher temperatures are likely to damage them for milling purposes. It is necessary to cool the dried beans immediately to 80° to 90° F. Accordingly, the lower part of a drying installation consists of a cooling section in which the beans continue their downward flow against a blast of cold air.

The usual storage facilities consist of a number of reinforced concrete silos and interstices which are served by horizontal belt conveyors overhead in the gallery and in the basement below the boots. Cleaning, elevating, and drying equipment is located in the head house at one end of the line of bins. The tanks often have thermocouples situated at various depths by means of which temperatures of the beans at any point may be determined from a central switchboard. Figure 1 shows a typical construction of this type having a total storage capacity of 2,500,000 bushels. Many mills have much smaller elevators and some have larger ones, but very few have sufficient capacity to hold a full year's supply of beans. Large amounts are also stored in smaller country elevators, usually nearer to the production areas. Considerable quantities of soybeans are occasionally stored in ship holds, particularly in Great Lakes steamers which must lie idle during the winter months.

Little has been published concerning the changes which occur in soybeans during storage and the effects which such changes have upon the subsequent processing operations. A number of theories regarding these changes are reviewed by Singer (178) and by Bredeman and Kummer (47). The use of plant operating data to follow the variations in properties of stored seed is difficult because of the differences between the beans harvested in successive years. It is well known, however, that the yield of oil from newly harvested beans is less than would be obtained from the same beans after several months' storage, and that the operation of pressing equipment must be altered at various times during the year to conform to the ever-changing condition of the stored soybeans.

3. Methods of processing soybeans

Only three methods are commonly used to process soybeans for oil and meal, namely continuous pressing (expellers and screw presses), hydraulic pressing, and solvent extraction. Table 2 contains data showing the relative importance of the three processes in the United States. The use of solvent extraction has gained in importance during recent years, and current construction work indicates that an even greater proportion of the 1941 and succeeding crops will be solvent-extracted. In the Orient, soybeans are crushed almost entirely by hydraulic presses or similar equipment, and in Europe solvent extraction is used almost exclusively.

Table 2. Soybeans processed by expeller, solvent, and hydraulic methods

Estimates based upon data compiled by Bureau of the Census
in cooperation with U. S. Regional Soybean Industrial Products Laboratory
January 1941

Crop Year	Expeller		Solvent		Hydraulic		Total	
(October to October)	Tons	Percent	Tons	Percent	Tons	Percent	Tons	Percent
1936-37	422,800	68.5	81,604	13.2	114,136	18.5	618,540	100.0
1937-38	637,532	70.1	155,591	17.1	116,167	12.8	909,290	100.0
1938-39	967,173	72.2	214,161	16.0	158,093	11.8	1,339,427	100.0
1939-40	1,274,016	74.4	346,055	20.2	92,081	5.4	1,712,152	100.0
1940-41	1,425,501	74.2	443,685	23.1	52,486	2.7	1,921,672	100.0

Those American mills which use hydraulic presses are or have been, for the most part, engaged primarily in crushing other oilseeds such as cottonseed and linseed. Such mills can be readily adapted to soybean crushing, but the unit crushing costs are said to be higher than those encountered in either the continuous press or the solvent mills. The higher costs are due largely to the increased amount of hand labor required for a batch type of operation.

Solvent extraction of soybeans has been carried out in batch equipment of several types, using a variety of solvents, but all American soybean mills which now use the solvent process employ continuous systems. Although considerable effort has been expended toward developing solvent processes which can be safely and economically operated on a small scale, the solvent extraction systems now used commercially appear best suited for large-scale operation, i.e., 50 tons or more of soybeans per day. One of the advantages of the solvent system is the high recovery of oil. While pressing methods yield residual meals containing 4.0 to 5.5 percent oil, solvent-extracted meal contains one percent or less oil.

Expellers and screw presses have capacities of approximately 20 tons of soybeans per 24 hours, and mills operate with any number of such presses installed side by side, depending upon the desired capacity. A few plants use only one press and, on the other hand, some of the large installations



Figure 1.- Elevators at a soybean processing mill.
(Courtesy of Central Soya Company)

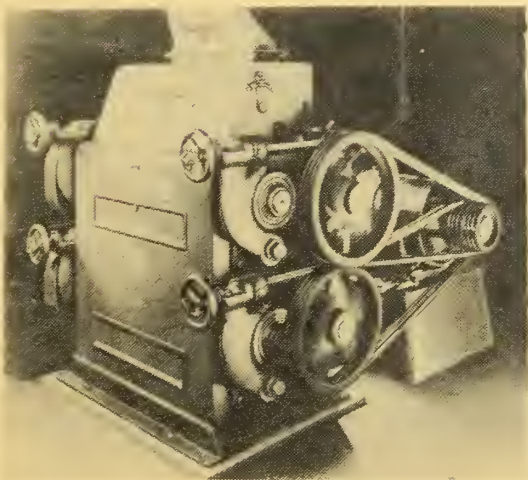


Figure 2.- Cracking rolls used to prepare soybeans for pressing in expellers or screw presses. (Courtesy of Allis-Chalmers Manufacturing Company)

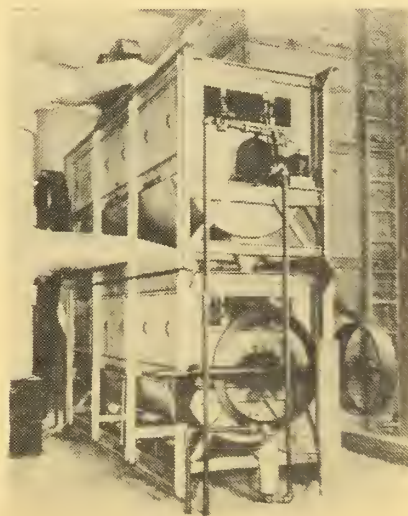


Figure 3.- Two steam-heated rotary driers connected in series, for drying cracked soybeans. (Courtesy of Allis-Chalmers Manufacturing Company)



include several dozen units. Because of the lower operating costs made possible by operating a large number of presses in a single mill, most operators of one-press plants have found it to their advantage to add one or more expellers or screw presses if it is at all possible to obtain sufficient bean supplies to ensure their uninterrupted operation.

Because of the high overhead associated with soybean processing operations, it is necessary to operate crushing equipment almost the year around in order to achieve minimum conversion costs. An expeller mill, for example, in 300 days' operations, would require approximately 200,000 bushels of beans per press, i.e., the entire production of 10,000 acres of typical soybean acreage for each expeller. In general, the choice of the type, size, and location of a soybean processing mill revolves largely around the amount of soybeans available and the accessibility of the consuming markets for the products. The latter factor is determined in many, if not most, cases by freight rates and the applicability of milling-in-transit privileges.

4. Processing by means of continuous presses

As shown in Table 2, approximately 75 percent of the annual soybean crush in the United States is now carried out by the use of expellers or screw presses. In this process the beans are withdrawn from storage and conveyed to the mill where they are weighed, re-cleaned, and fed to corrugated rolls which crack them into small particles. The roller mills themselves are similar in most respects to those used elsewhere in the milling industry. They usually consist of two or three adjustable pairs of chilled steel rolls 9 or 10 inches in diameter and 14 to 42 inches long, depending on the capacity. Most of these rolls have saw-tooth corrugations running sharp-to-sharp with considerable differential in speed (56).

The average size to which beans are cracked varies considerably from plant to plant, and although the particle size and the degree of size uniformity appear definitely to influence certain aspects of the performance of the presses, reasonably satisfactory operation can be secured over a very wide range of size. A sample which yields a screen analysis averaging between 16 and 10 mesh might be considered typical although this should not by any means be regarded as standard. Figure 2 shows a set of cracking rolls commonly used for this operation.

In some mills, a large portion of the hulls is removed by screening, aspiration, centrifugal treatment, or other means after the soybeans are cracked. This is usually the practice when the meal is destined for human consumption. In some cases, it has been found advantageous to remove the hulls of certain colored varieties of soybeans in order to obtain an acceptable color in the oil. The separated hulls can be ground and mixed with that portion of the meal which is sold for livestock feeding. Hull separation, however, is carried out on only a relatively small scale.

Satisfactory operation of continuous presses requires that the beans be both hot and dry, so the cracking rolls are immediately followed by rotary steam-heated driers. A typical installation is shown in Figure 3. The

more commonly used types employ rotating steam coils and scrapers within a stationary shell, but a number of other types are successfully used. They are often operated in banks of two or more units in series. Moisture is reduced to between 2 and 5 percent, generally approximating the former figure, and temperatures of the discharged product are usually between 240° and 270° F. It is necessary to apply a certain amount of forced ventilation in order to remove water vapor from the driers. Satisfactory operation is obtainable with a draft barely sufficient to maintain the stack gases above the dew point. A dust separator is essential to such an installation.

The drying of granulated soybeans does not appear to have received much attention, from a theoretical viewpoint. Design of the driers now used seems to have been accomplished principally by the "trial and error" method, and consequently, the literature contains little, if any, information relative to equilibrium moisture contents at various temperatures and humidities, to the causes and prevention of case-hardening, or to the effects of the controllable factors upon drying rates.

Present drying practice as used in pressing soybeans results in a non-uniform product because insufficient time is permitted for equalization of unsteady-state temperature and moisture distributions set up within the individual grains. The usual practice, therefore, is to "temper" the dry beans before pressing by holding them at an elevated temperature for a period sufficient both for dissipation of the unsteady-state conditions and for "cooking" the protein to the proper physical condition for pressing. This operation is accomplished by slowly conveying the charge through one to three steam-jacketed troughs or bins designed to provide ample retention time. A separate set of tempering apparatus is attached to each press, and the cracked beans discharged from the driers are immediately transported to these by means of an overhead screw conveyor and spout system arranged to serve all the machines in the press line. In the typical press-room arrangement, the overhead conveyors terminate in an overflow or "run-around" bin at the end of the press line. This receives excess feed which the expellers are not able to handle, and the resulting excess is returned to the beginning of the line by means of the "run-around" screw conveyor located beneath the floor. The tempering troughs discharge directly into the pressing screws of the expellers or screw presses. Steam is ordinarily supplied to both the driers and tempering troughs at a pressure of approximately 125 pounds per square inch.

Although a considerable number of continuous presses are or have been on the market, only two makes are commonly used on soybeans in this country, i.e., the Anderson expeller and the French screw press. However, a number of other continuous presses have been placed on the market from time to time. The various makes include:

1. The Anderson expeller manufactured by the V. D. Anderson Company, 1935 West 96th Street, Cleveland, Ohio.
2. The French screw press, manufactured by the French Oil Mill Machinery Company, Piqua, Ohio.

3. The Burrus rotor press, manufactured by the Davidson-Kennedy Company, 1090 Jefferson Street, N. W., Atlanta, Georgia.
4. The Hiller high pressure continuous press (104), until recently manufactured by the Santa Cruz Oil Corporation, San Francisco, California. Patents for this press are now reportedly owned by the V. D. Anderson Company.
5. The Sohler and Elbex screw presses, manufactured by the Fried. Krupp Grusonwerk Akt.-Ges., Magdeburg, Germany.
6. The MSP expeller press, manufactured by the Lenin Memorial Factory in U.S.S.R.
7. The Müller screw press, manufactured by Fritz Müller, Esslingen, Germany.
8. The Maxoil expeller, manufactured by Rose, Downs, and Thompson Ltd., Hull, England.

The Anderson expeller.

Figure 4 shows the Anderson Super Duo expeller with its component parts labeled. Pressing is accomplished by means of a worm shaft continuously rotating within a pressing cylinder or cage composed of closely spaced steel bars. The action is not unlike that of a household meat grinder. Pressure of 8 to 10 tons per square inch is developed partly because of an irregular design of the worm shaft and partly by means of an adjustable orifice or choke with which the cake discharge opening of the pressing cylinder can be constricted. The internal pressure and high temperature plasticize the previously cooked protein and cause the oil to flow out between the barrel bars. Sufficient frictional heat is created to toast the residual cake to a brown color, and the higher temperatures thus developed are conducive to easy drainage of oil out of the compressed charge.

The Super Duo expeller is one of the Anderson line of continuous presses which includes or has included models designated as No. 1, RB, Red Lion, Duo, Super Duo, and Duplex Super Duo. Of these, the Duo and Super Duo are the most generally employed for soybeans, but many RB presses and a few No. 1's are still being used for this purpose. The Duo expeller resembles the Super Duo in most respects but is of lighter construction and has a lower capacity.

Duo and Super Duo presses actually employ two pressing cylinders. The main barrel is horizontal and is fed from a smaller vertical drainage barrel which receives hot beans from the tempering apparatus and subjects them to preliminary pressure before forcing them into the main barrel. The horizontal worm shaft is driven at a speed of about 16 revolutions per minute by means of a 30- or 40-horsepower gear-motor, and its thrust is carried by a roller bearing located at the discharge end of the shaft. The vertical worm shaft is driven from above by a bevel gear and chain drive combination, designated "hopper feeder mechanism" in Figure 4. These presses, when installed to process soybeans, are usually equipped with three tempering troughs, 10 inches deep by about 10 feet long.

In order to maintain low barrel temperature, the Super Duo employs so-called "oil cooling" which is illustrated in Figure 4. Oil pressed in both cages is collected beneath the main barrel where it fills a trough to the height of the "oil discharge" overflow opening. A small pump circulates the oil thus collected at a rate of about 18 gallons per minute through a heat exchanger where it is water-cooled to 170° to 200° F. The cool oil is then used to flush both barrels, lowering their temperatures from upwards of 300° to about 200° F., and at the same time, washing the cages free of any accumulations of fine meal particles or "foots".

The French screw press

The French screw press as shown in Figure 5 also uses a powerful worm revolving within a press cage, but it differs considerably from the Anderson expeller in details of construction and operation. A single tempering trough, 28 inches in diameter, is employed. Instead of a vertical worm for pre-pressing the material before it enters the main barrel, this machine uses two screws revolving within the same horizontal barrel. The tempered beans fall from the steam-jacketed trough into the feeder worm which rotates at about 30 r.p.m. and presses out approximately half of the oil. The charge is then forced into the main screw revolving at 15 r.p.m. where it receives the final pressing and from which the cake is ejected through a cone type of adjustable pressure orifice. The two worms turn concentrically about a common axis and are both driven from a gear box located at the inlet end of the machine. They are provided with separate thrust bearings located in the gear case.

In many French screw presses, coarse foots are removed from the oil as it drips from the barrel by straining through a slowly traveling endless screen beneath the pressing cage. The retained particles (foots) are dumped into a conveyor which returns them, via the "run-around" bin, to be re-pressed after mixing with the feed. Most French screw presses are provided with water cooled cages, the cooling water being circulated through ports in the steel rings which form the cradle supporting the barrel bars. There are numerous additional structural features wherein the French and Anderson machines differ, and for an elaboration of these the interested reader is referred to the literature published by the respective manufacturers.

Operation of continuous presses

Regardless of the make of continuous press employed, the resulting crude oil contains large amounts of suspended meal particles. A large part of these is removed by passing the oil through vibrating screens, revolving reels, or similar separating devices. The finest particles are filtered out, generally in filter presses, either with or without the addition of filter aids. The solids thus separated are fed into the "run-around" bin and are thus re-pressed. The filtered crude oil is run into storage tanks or to tank cars for shipment (125).

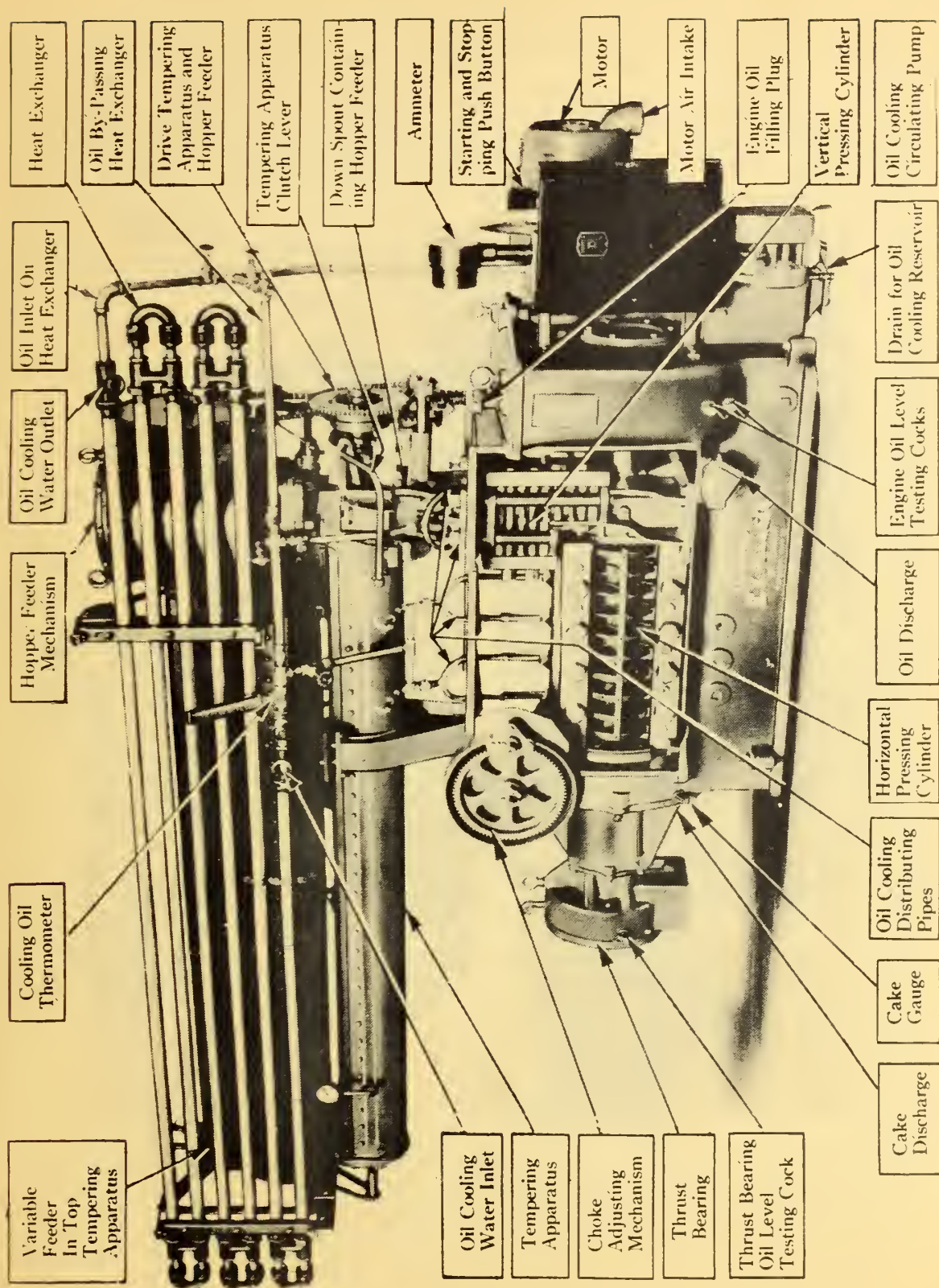
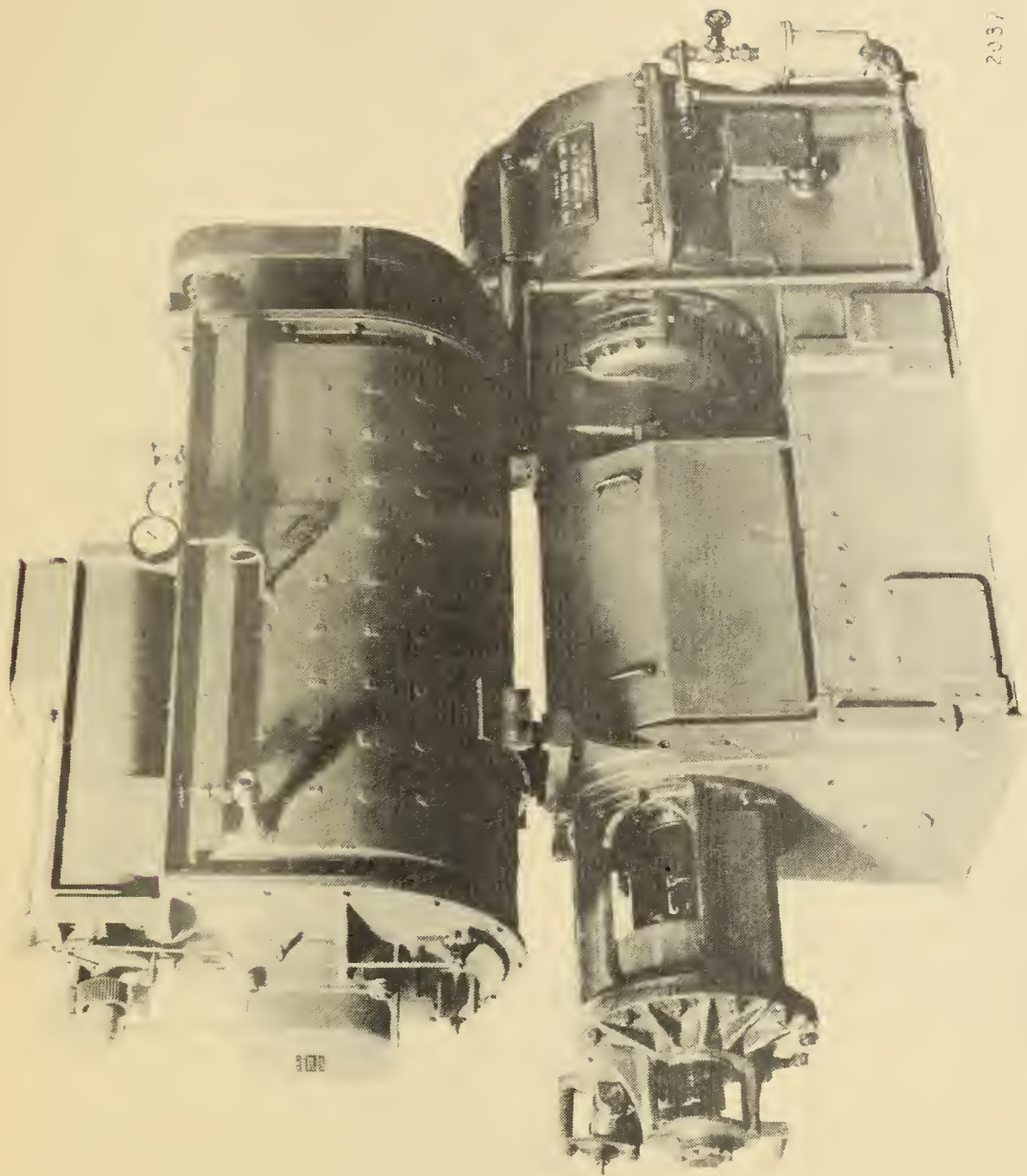


Figure 4.- Anderson Super-Duo oil expeller. (Courtesy of V. D. Anderson Company)



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Figure 5.-- The French screw press. (Courtesy of French Oil Mill Machinery Company)

The cake produced by continuous presses emerges as irregularly shaped fragments, which while still hot, emit a strong and mildly pleasant odor characteristic of soybean mills using this process. The odorous constituents are strongly adsorbed by articles of clothing, etc.

The freshly ejected cake contains 4 to 5 percent of oil and approximately 2 percent of moisture. Since it is quite hot, it cannot be stored in bulk without first being cooled nearly to room temperature. Otherwise, it rapidly heats spontaneously until combustion takes place, a phenomenon which has caused occasional destructive fires in processing mills. (14). Cooling can be accomplished by a wide variety of methods, the essential operations being thorough aeration and addition of sufficient water to produce a final meal containing 10 to 12 percent of moisture. There are a number of cake coolers on the market, usually consisting of a horizontal cylindrical shell which is well ventilated and which contains a rotor with stirring blades. The cooling is effected mainly by evaporation of water which is sprayed onto the hot cake. In some installations, cooling is accomplished simply by passing the cake through long open conveyors, with the addition of water. In order to increase the ease of water absorption, the hot cake is sometimes first run through a corn crusher or similar type of cake breaker. The cooled cake is ground into meal in hammer mills and is then conveyed to storage bins, sacking machines, or bulk car loaders.

Many soybean mills are operated in conjunction with feed mixing plants, and a large portion of the meal therefore never reaches the market as such. It is often marketed in pellet form in various sizes, either alone or blended with a mineral supplement. In mixed feeds, it is sold in an extremely wide variety of products. Soybean meal shipments are ordinarily made either in 100-pound bags or in bulk.

In most respects, the operation of expellers and screw presses is an art concerning which no fixed rules can be given. The judgment of the operator, developed by years of experience, is usually the principal factor contributing to the efficiency of a mill's production. A skilled superintendent or foreman, however, relies to a great extent upon both physical and chemical measurements as guides toward the proper adjustment of the many items of process equipment throughout the mill. It is for this reason that all large processing plants include well equipped chemical laboratories and are provided with the many specialized instruments requisite both to intelligent operation on and to accurate accounting of raw materials and products (143).

The use of expellers or screw presses is, at present, a fairly standard method for processing soybeans, especially in those mills having a daily capacity of 50 tons or less. A mill can operate with any number of such presses, all receiving dried beans from the same conveyor system and discharging oil and cake into common pipes or chutes. Figure 6 shows the interior of a very large mill using nearly 50 Anderson expellers and Figure 7 shows an installation of six French screw presses in a mill which in size might be considered quite typical of the present-day American processing plants. By this method, one bushel of beans (60 pounds) yields approximately 9 pounds of crude oil and 48 to 49 pounds of meal, the latter containing 41 to 44 percent protein and 12 percent moisture.

The temperatures and moisture contents of the beans at various stages in the process vary considerably from plant to plant, but the following might be considered typical operating conditions:

Moisture content of beans entering drier	10 - 15 percent
Moisture content of beans leaving drier	2.5 percent
Moisture content of beans entering press cage	2.5 percent
Temperature of beans leaving drier	270° F.
Temperature of beans entering press cage	270° F.
Temperature of barrel bars in uncooled cage	310° F.
Temperature of surface of freshly pressed cake	310° F.
Oil content of cake, on 10 percent moisture basis	4.4 percent
Protein content of cake, on 10 percent moisture basis	43.0 percent
Moisture content of freshly pressed cake	2.0 percent

The storage and shipment of crude soybean oil is generally attended by difficulties resulting from the formation of phosphatide-containing sludges in the tank bottoms. The maximum permissible amount of such sludge is specified in the trading rules which apply to soybean oil marketing, and sludge in excess of that permitted results in application of discounts. The amount of precipitate formed varies over wide limits and is governed by such factors as the quality of the beans, the storage conditions, the pressing technique, etc. (181). Crude oils which have been freshly pressed and filtered to yield a crystal-clear product gradually undergo precipitation of the dissolved phosphatides unless some treatment is given to remove the sludge-forming materials (87). This can be effected by washing the oil with water to hydrate the phosphatides, throwing them out of solution. The sludge thus formed can be rapidly separated from the oil by centrifuging. By using some alkali in the wash water, a partial refining can be effected, and some expeller-type mills have installed equipment for this purpose. More detailed information is given in the section describing phosphatides and phosphatide processing.

As is the case with many types of processing of agricultural products, the operation of expeller or screw press soybean mills is subject to the danger of dust explosions. The relative explosibilities of various dusts encountered in soybean processing were reported by Price (146) and were compared with those of other dusts.

The drying and tempering of soybeans for crushing in expellers or screw presses appears to be necessary in order to have sufficient frictional resistance built up during the subsequent passage of the tempered beans through the pressing cage. In this respect, soybean crushing is different from that of most other oilseeds wherein the precooking process is done in such a way that the seed meats are softened and the cell walls are weakened rather than toughened (124, 136, 144, 205).

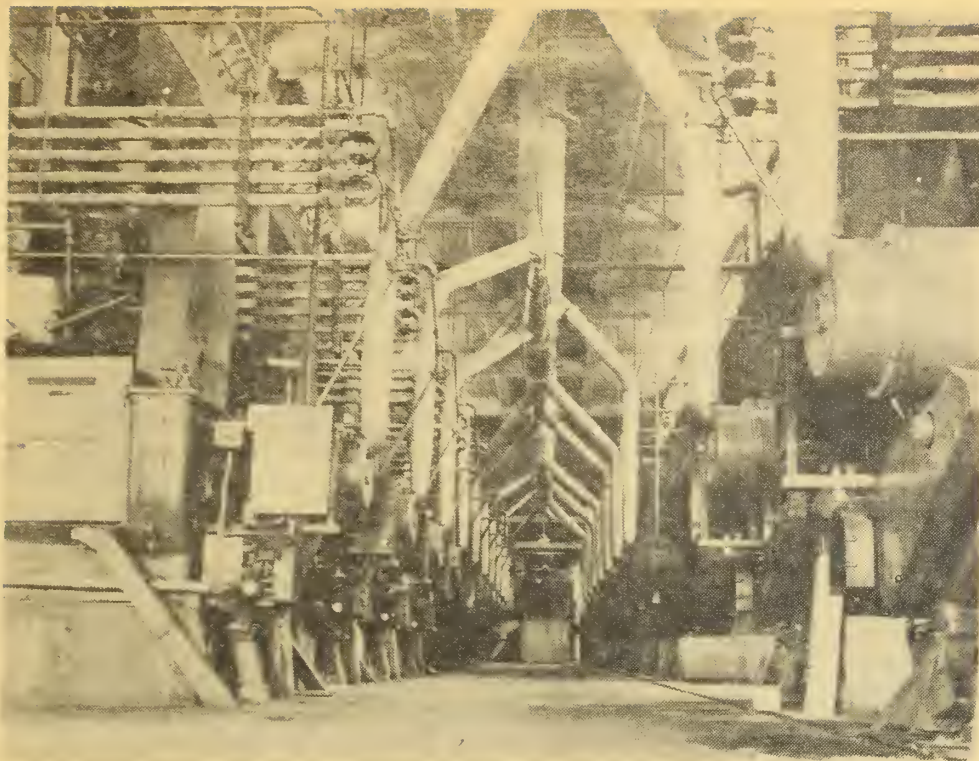


Figure 6.- An installation of Anderson expellers crushing soybeans. (Courtesy of V. D. Anderson Company)

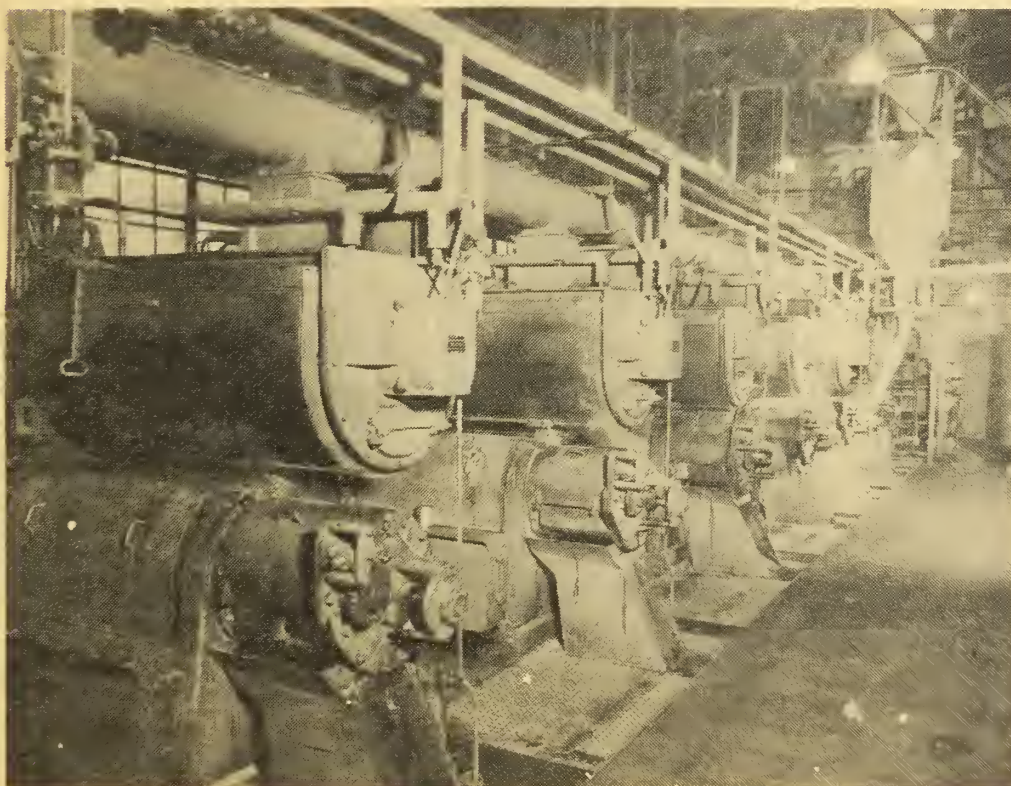


Figure 7.- A battery of French screw presses crushing soybeans. (Courtesy of French Oil Mill Machinery Company)

Several theories have been proposed to explain the roles of water, proteins, cell wall constituents, etc., in the process of pre-cooking oilseeds prior to the removal of the oil. These are reviewed by Heublum and Japhe (98), Singer (179), and Goldovskii (83).

In Russia, two of the more modern hydraulic press methods of oil production have been developed as the result of chemical studies on the role of moisture during cooking. These are of interest because of their relation to research now being carried on in this country with a view toward improving the pressing processes used on soybeans, cottonseed, linseed, etc. The Skipin (180) process comprises the precooking of the oil-bearing material in the presence of a very high percentage of water. Under these conditions, a large share of the contained oil is released and drains from the meats before the pressing operation. It has been successfully applied to the processing of castor beans, sunflower seed, hemp seed, cottonseed, cedar nuts, sesame seed, and peanuts in order to increase the capacity of a given press installation.

The Iljin process is employed to obtain a greater yield of oil from linseed, sesame seed, sunflower seed, etc. The material is treated with steam in such a way that it can be given a pre-pressing to remove 80 percent of the oil at relatively low pressure and at a relatively high moisture content without undue oozing or flowing of the cake. The residual cakes are broken up, treated with superheated steam, and re-pressed in the normal manner.

5. Processing by means of continuous solvent extractors

At present, about 20 percent of the soybean processing in this country is carried out by means of volatile hydrocarbon solvents in a variety of equipment designed for continuous operation. Batch solvent extraction is still employed to some extent in other countries, but not in the United States. The continuous soybean extraction systems now in commercial use in this country include the Pollman (Hansa-Mühle), Hildebrandt, Allis-Chalmers, French, and Ford extractors. The variety and sequence of operations are more or less the same in all these systems, their most characteristic features being chiefly the designs of the individual extractors themselves, i.e., the methods of contacting beans with solvent in order to dissolve out the oil. A number of general references describing the use of solvent extraction equipment are listed in the bibliography (39, 45, 84, 94, 114, 135, 177, 192, 227).

Although continuous presses operate upon beans which have been subjected only to granulation, such material, when used in solvent equipment and ground sufficiently fine to secure efficient oil removal, tends to clog filters and to produce solvent channeling and consequent non-uniform extraction. It is therefore the practice to roll the beans into thin flakes similar in some respects to those produced in the hydraulic pressing of soybeans, cottonseed, etc. They are first cracked to a size which is determined by the desired dimensions of the final flakes, and if very dry, they are moistened by addition of direct steam. It is also customary to heat the beans, since the

rolling operation is facilitated by both high temperatures and a high moisture content. Corrugated rolls of the same type as are used in pressing plants are used for cracking. In most mills the flaking is accomplished with a single pair of smooth rolls, 1-1/2 to 3-1/2 feet in diameter and about the same in length. These are driven at approximately 400 r.p.m., either at equal speeds or with a differential which may be extremely slight or as high as 3:2. The desired characteristics of individual flakes, i.e., thickness, strength, size, etc., vary considerably, depending upon the type of extractor to be used, and they may be controlled by proper regulation of the pre-cracking, moisture content, temperature, roll spacing, etc.

Soybeans are ideally suited for solvent extraction since they can be rolled into thin, firm flakes which are sufficiently rugged to withstand the solvent treatment without disintegrating to a fine powder. One of the principal difficulties encountered in the extraction of cottonseed (131), linseed and other oilseeds results from the solution of the intercellular binder during extraction with consequent disintegration of the individual flakes. The large amount of finely divided material thus produced results in compacting of the solids and uneven extraction due to channeling. It is for this reason that continuous solvent extraction has been applied to soybeans to a much greater extent than it has to other oil bearing seeds.

In rolling soybeans for solvent extraction it is essential to produce as thin a flake as possible, consistent with preserving considerable strength. In systems where mechanical agitation of the flakes is kept to a minimum, a thickness of about 0.007 inch is found satisfactory. In other systems where the flakes are subjected to considerable handling, as in extractors which propel the charge through the solvent with screw conveyors, flake thicknesses of 0.009 to 0.015 inch are commonly employed. In either case, maximum flake strength results from rolling moist beans through a single pass mill. The 5-high roller mills used in the hydraulic milling of oilseeds cause so much rupturing of cell walls by the repeated rolling that the resulting flakes are too fragile.

The Hildebrandt system

Although the results of individual operations as carried out in various solvent systems are somewhat similar, considerable variation exists in the design, equipment, and method of carrying out the necessary steps of the process. For illustration, however, the Hildebrandt system (100, 101, 102, 103) is a satisfactory example. A flowsheet of this process, starting with the conveyor connecting the flaking rolls to the extraction tower, 1, is shown in Figure 8.

The extraction column is shown in greater detail in Figure 9. The unit is a U-shaped tube, 3, 5, 7, into which bean flakes enter at 1 and through which they are propelled by the perforated screw conveyors 2, 4, and 6. These are rotated at different speeds by means of explosion-proof gear-motors, the relative motions being controlled to produce considerable compacting in the "pressure chamber," 5. Guide rails, 8, may be provided in the ascending leg, 7, of the tower to prevent rotation of the charge as it is carried upward. The solvent, which is usually hexane, is pumped through

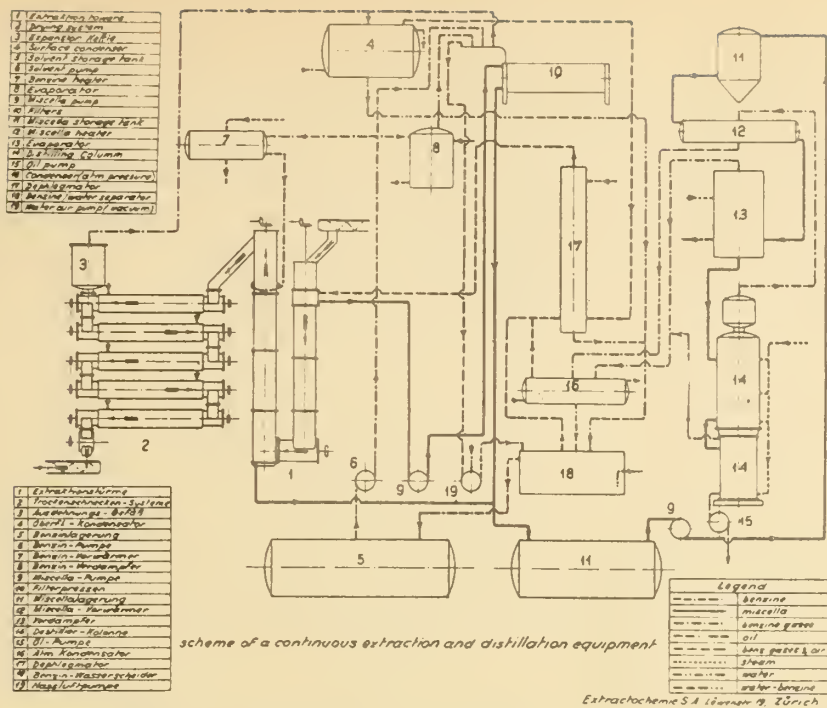


Figure 8.- Flowsheet of the Hildebrandt system of solvent extraction. (Courtesy of Sieck and Drucker, Inc.)

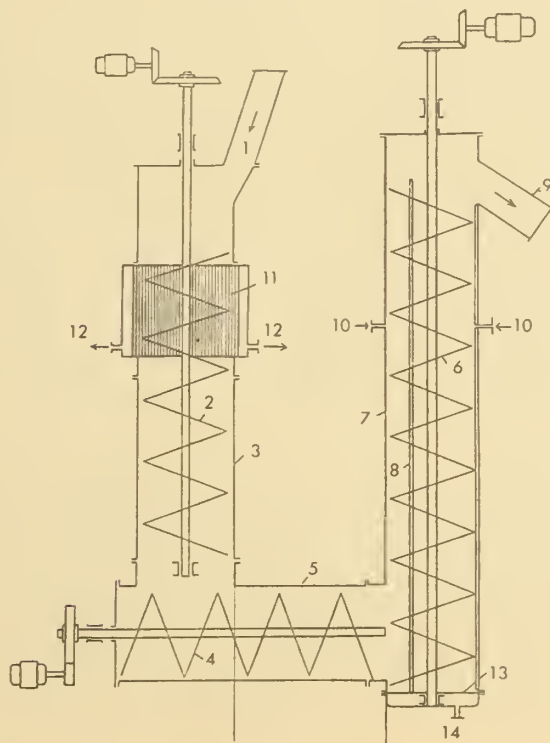


Figure 9.- The Hildebrandt extractor.

the apparatus in countercurrent flow, entering at 10. The oil-solvent mixture, or miscella, is discharged at 12 after passing through the strainer, 11. The strainer is a cylindrical sheet perforated with vertical slots which are narrower at the inside edge than at the outside. This shape of opening prevents solid particles in the exit miscella from clogging the openings. In addition, the screw flight, 2, is accurately machined to provide a clearance of only a few thousandths of an inch between its outer edge and the inner screen surface, providing a wiping or self-cleaning action.

The upper part of the ascending leg, 7, acts as a drainage zone for removal of most of the entrained solvent from the oil-free flakes. At 9, the wet extracted flakes are discharged into meal driers shown at 2 in Figure 8. These are steam-jacketed conveyor sections wherein residual solvent is driven off to be condensed in the surface condenser, 4, and returned to the system. The expansion kettle, 3, is provided to minimize the amount of dust carried into the surface condenser by the solvent vapor. If protein dusts are permitted to enter the separator, 18, which removes water from the condensed solvent, serious emulsion formation will result.

The meal drying equipment consists of five horizontal, steam-jacketed cylinders, arranged in series, through which the spent flakes are conveyed by rotating screws. A small amount of direct steam is often used in the final or fifth pass of the meal driers. The discharged meal contains 0.5 to 1.0 percent oil and over 44 percent of protein. Since it is used almost entirely as a feed supplement, it is ordinarily given an additional toasting to increase its palatability and the nutritive value of the protein (96).

Although it is claimed that toasting solvent-extracted meal greatly enhances its feeding value, the practice was introduced to the American industry largely as a measure toward overcoming the consumer prejudice against oilseed meals having a light color. As pointed out by Heublum and Japhe (98), the production of a characteristic color associated with "toasting" and the complete denaturing of the proteins can be obtained by the combined effect of moisture and heat. Neither agent, per se, is very effective. The stack type of cooker, as used in other branches of the oilseed processing industry, is well suited for heating extracted flakes in the presence of a large excess of moisture. Although this equipment is not shown in Figure 8, it is described and illustrated under "Hydraulic pressing," page 26, Figure 24.

The extracted flakes from the meal driers are introduced into the uppermost stack of the cooker, and the moisture content is raised to 15 to 18 percent by adding steam and water. The cooking takes place in the lower compartments which are provided with some degree of ventilation. According to Hayward (97) the flakes are in the cooker for approximately 75 minutes at a maximum temperature of 220° F. They emerge containing 10 to 12 percent moisture and are passed through meal cooling equipment to reduce their temperature to approximately 80° F.

Figure 8 indicates also the course of solvent (petroleum hydrocarbons, principally hexane) through the Hildebrandt system. From a tank, 5, it is pumped through a preheater, 7, where it is heated by steam to about 120° F.

and from which it flows to the extractor. After countercurrently extracting oil from the flakes, the resulting miscella, containing approximately 20 percent oil, leaves at a point so located that there is always a sufficient layer of fresh bean flakes above the miscella outlet to prevent escape of solvent vapor through the flake charging mechanism. The ratio of solvent input to soybean input on a weight basis is roughly of the order of one to one.

The complete removal of solvent from the oil must be performed with great care, particularly in the United States where the flavor standards for edible oils are very high. It is especially important to avoid over-heating the oil by continued exposure to hot surfaces. The solvent distillation is therefore carried out in several steps. The bulk of the solvent may be easily removed by any of a considerable variety of evaporating apparatus, but rather specialized distillation equipment is necessary for removing the last 5 or 10 percent of solvent from the miscella. Bubble cap columns, vertical packed columns, and evaporators constructed to maintain continuously moving thin films of oil over the evaporating surfaces are effective for removing these last few percent of solvent. It is also essential to reduce the amount of fines contained in the miscella so that the final distillation can be carried out effectively. This point is discussed by Bilbe (25) who describes settling, filtration, and centrifugal clarifying methods.

In the Hildebrandt system, the miscella is filtered through specially constructed filter presses, 10, and pumped to intermediate storage tanks, 11. It then passes through a preheater, 12, where it is warmed by vapors from the main solvent distilling equipment, and thence, in many installations, to a preliminary steam tube evaporator which removes about 10 percent of the solvent. The rest of the solvent is removed in the distillation column, 14. In this apparatus (37), the miscella enters at the top and passes downward successively through three evaporator sections, each of which is heated by a pancake steam coil. The vapors pass upward through a dephlegmator and then through the miscella preheater, 12. The undistilled product from the lowest evaporator contains approximately 10 percent solvent and runs into the lower or stripping section. This contains several bubble cap plates, and the oil is stripped of all traces of solvent by means of counterflowing steam. The solvent vapors pass to the condenser, 16, and the condensate runs into the water separating tank, 18, from which it returns to the solvent storage tank, 5.

The oil leaves the solvent-distillation equipment at a temperature of about 200° F. and is in the form of a very fluid emulsion with water. The formation of a water emulsion can be prevented, if desired, by the judicious use of super-heated steam. However, the water causes the phosphatides to become hydrated and to be precipitated out of solution. By running the emulsion through a continuous separating centrifuge the oil is clarified and the phosphatides are discharged as an oily sludge which, in many mills, is used for the production of commercial lecithin. Crude oil, before centrifuging, usually contains 0.05 to 0.10 percent of phosphorus, and the process of hydration and subsequent centrifuging, as generally employed, produces a clarified oil having a phosphorus content of 0.003 to 0.008 percent. Such oil can often be sold at a slight premium over the unwashed crude oils.

Figure 10 shows a Hildebrandt extraction tower in side elevation, the second and third floors of the plant being cut away to provide an unobstructed view of the entire unit. Figure 11 shows a pair of these columns with their respective sets of meal driers arranged vertically between them. The solvent distillation equipment is shown in Figure 12. These units are regularly supplied in two sizes having nominal capacities, respectively, of 55 and 110 metric tons of raw material per 24 hours. Where larger capacities are required, several units are installed.

The Bollmann system

The Bollmann or Hansa-Mühle extractor (27, 28, 29, 67, 91, 92) is shown in Figure 13. A number of baskets, b, having perforated bottoms, are attached to a pair of endless chains, a, which encircle and are driven by sprocket wheels. A charging hopper, c, introduces a predetermined amount of bean flakes into each basket as it starts down the descending side of the apparatus. Freshly filled baskets are moved slowly around the circuit in the direction indicated by arrows while the oil is dissolved from the beans by a spray of solvent. Upon reaching the top of the ascending side, the baskets automatically invert and dump the extracted meal into a discharge hopper, d. The filling and emptying mechanisms are shown more clearly in Figure 14. A pair of screw conveyors removes the spent flakes from the discharge hopper and feeds them to the meal driers which are located outside and alongside the vapor-tight steel housing which encloses the complete basket system.

Fresh solvent, e.g., hexane, is sprayed onto the ascending line of baskets near the top and percolates downward, successively washing the contents of each container in countercurrent flow. The resulting solvent-oil mixture collects in a sump, e, which comprises one side of the bottom of the housing. This so-called "half-miscella" is pumped to a storage tank, f, and subsequently is sprayed onto the top of the descending chain of baskets to wash them in parallel flow. "Full miscella" collects in a sump, g, whence it is pumped to bag filters and then to miscella storage tanks.

The full miscella contains 20 to 30 percent of oil and passes through a heat exchanger where it is preheated nearly to the boiling point by vapors from the distillation equipment. It is concentrated to approximately 50 percent oil content in a series of two or three steam tube evaporators. A further concentration to 90 to 95 percent oil is then effected in a "drip" type of evaporator in which the oil runs, in thin films down the inner surfaces of vertical tubes surrounded by steam. The "drip" tubes feed into a flash chamber at the bottom. Final stripping of the solvent from the oil takes place in a packed tower or in an additional "drip" type of evaporator in which it is countercurrently scrubbed with steam under vacuum. The crude oil contains emulsified water and hydrated phosphatides which are removed by centrifuging, as previously described.

The spent flakes contain moisture and entrained solvent which are removed, the latter practically completely, by successive passages through six meal driers or "Schneckens." These are horizontal steam-jacketed screw conveyors arranged in vertical banks. The bottom "Schneckens" feed into a

deodorizing drum which is a jacketed steam drier having a steam-heated rotating coil equipped with scrapers for propelling the charge. Direct steam is admitted to assist in the deodorization. Finally, the solvent-free flakes are toasted in the presence of large amounts of moisture in a stack cooker, as previously described. The vapors given off from the meal driers pass through dust collecting equipment before being condensed and fed into the water separating tank.

In the Pollmann system, the flakes rest on perforated plates and are not agitated during the extraction process. The percolation method of operation affords considerable "self-filtration" of the miscella, minimizing the difficulties resulting from "fines" in the miscella. For these reasons, it is customary to use thinner and smaller flakes than are employed by the systems in which the flakes are completely immersed in and propelled through the solvent by screw conveyors. Usually, the baskets are moved through the extractor at the rate of about one revolution per hour, and solvent is sprayed onto the flakes at a rate corresponding to one pound of solvent per pound of beans processed. In European mills, slightly different operating conditions are employed, principally because Manchurian soybeans, which have heretofore constituted the bulk of their operations, are quite different from American beans in their physical behavior during processing. The Bollmann or Hansa-Mühle extractor has been built in sizes having capacities of from 50 to 500 tons of soybeans per day. Figure 15 shows an installation of the Bollmann system. Two vertical banks of "Schneckens" surmounting a deodorizing drum may be seen immediately behind the stairway in the foreground.

Extraction system of The French Oil Mill Machinery Company

The Hildebrandt and Pollmann systems are both of German origin and manufacture and are widely used throughout Europe for processing a variety of oilseeds and oilseed press cakes. In recent years there have been developed several American systems, some of which are now in successful operation.

The French Oil Mill Machinery Company has installed solvent extraction equipment which resembles the Bollmann system in most respects. Because of the close resemblance, a detailed description will not be given. The baskets have specially designed solvent ducts into which reciprocating solvent spray nozzles inject the solvent while the baskets are in motion. The baskets are built with false bottoms constructed to distribute the solvent evenly over the next lower basket. This makes special precautions to avoid channeling unnecessary. The mechanical devices for guiding, charging, inverting, and dumping the buckets are also somewhat different from those employed by the Bollmann system. One installation of this system extracts approximately 130 tons of soybeans per day.

The Allis-Chalmers extractor

An early edition of the Allis-Chalmers (38, 41, 42, 68) extractor is shown in greatly simplified form in Figure 16. A vertical cylindrical column

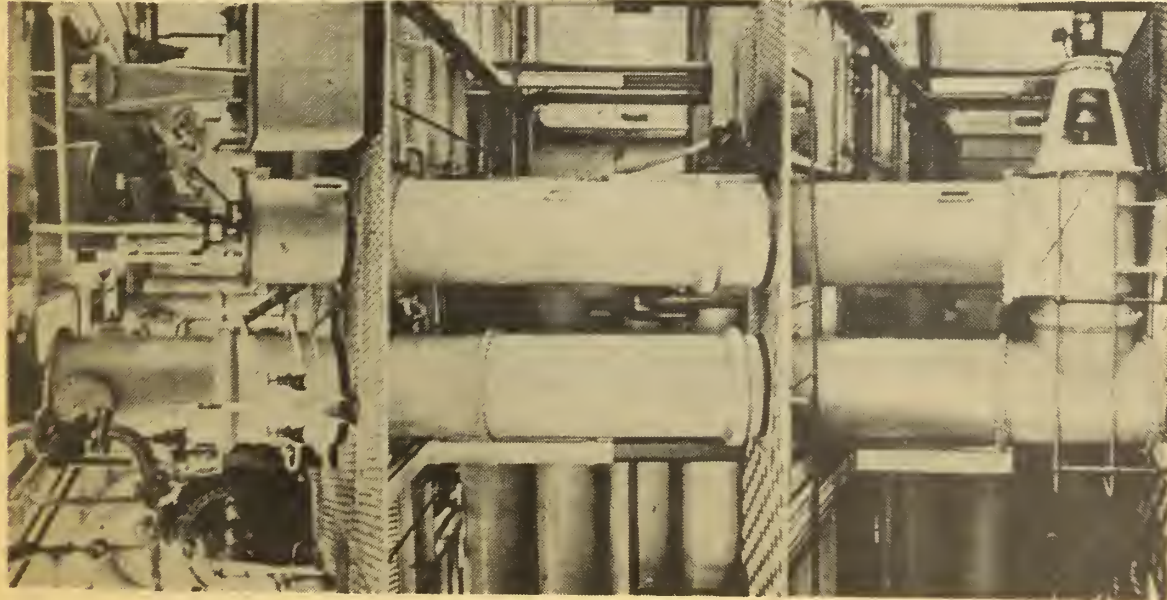


Figure 10.- Side elevation on Hildebrandt extractor, with floors out away to provide full view. (Courtesy of Sieck and Drucker, Inc.)

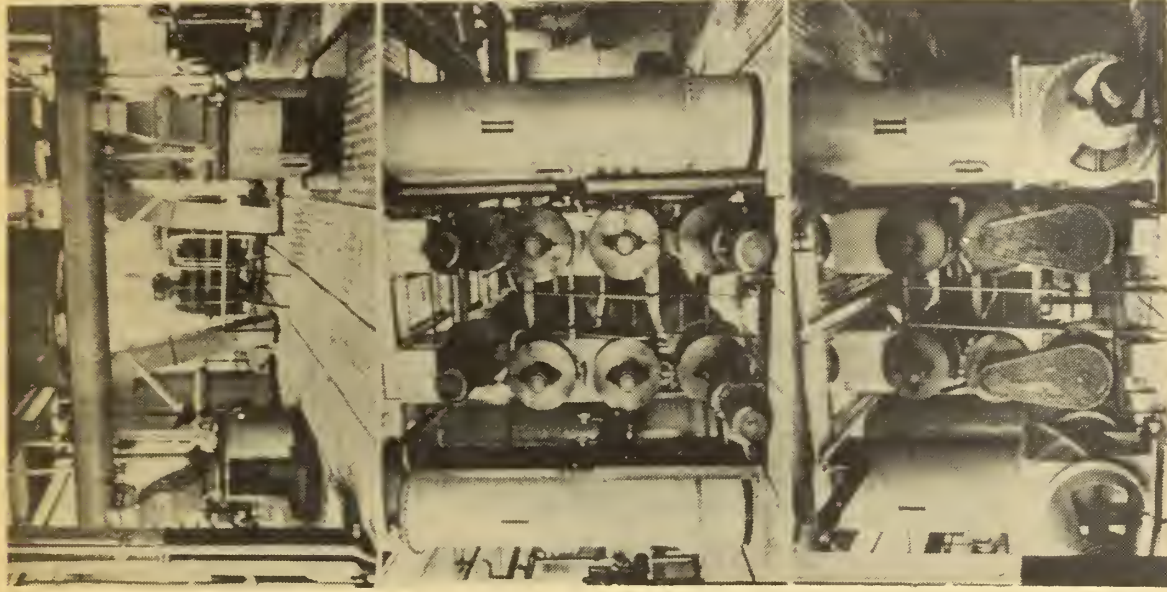


Figure 11.- Installation of two Hildebrandt extraction units. (Courtesy of Sieck and Drucker, Inc.)

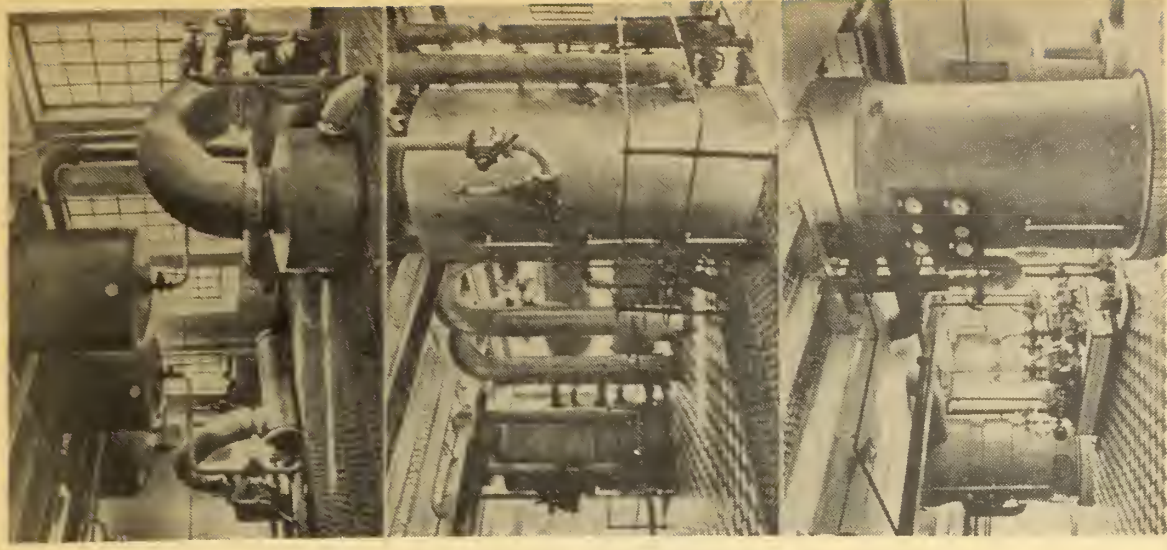


Figure 12.- Solvent distillation equipment of Hildebrandt extraction system. (Courtesy of Sieck and Drucker, Inc.)

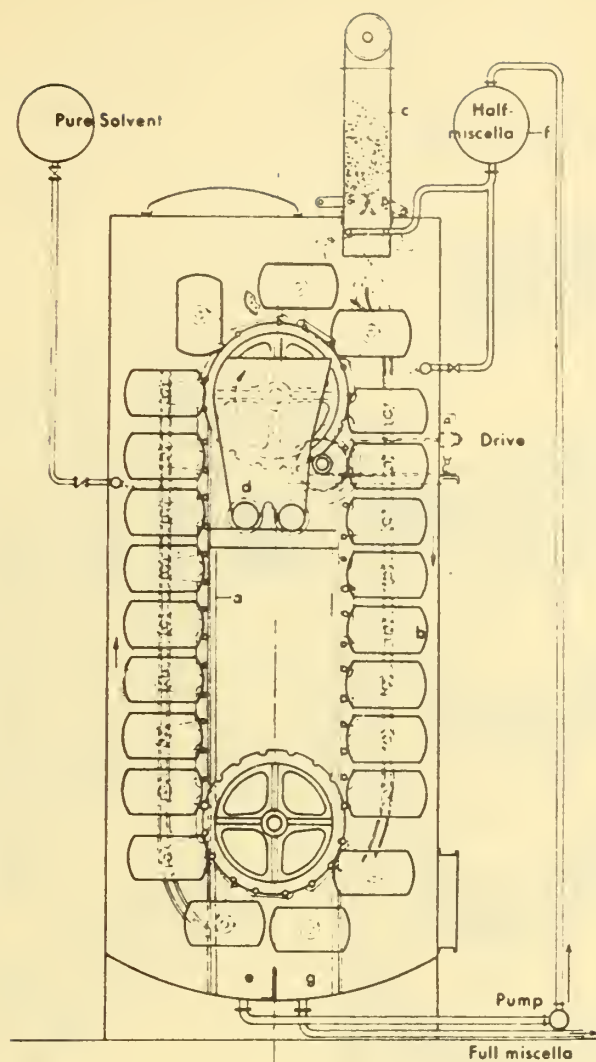


Figure 13.- The Bollman system of solvent extraction. (Courtesy of Albert H. Bruecke)

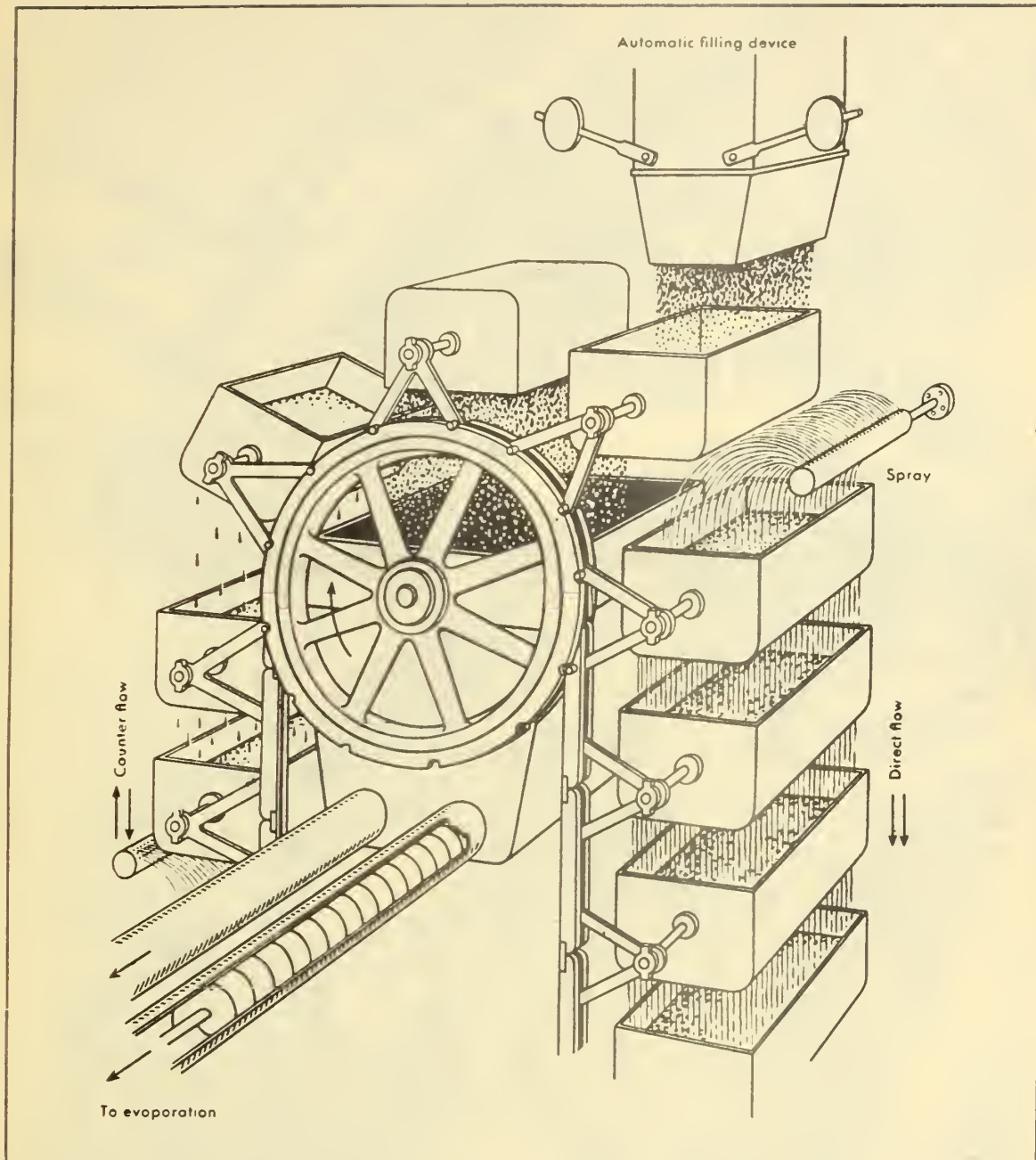


Figure 14.- Basket filling and discharging mechanism of the Bollman extractor. (Courtesy of Albert H. Bruecke)

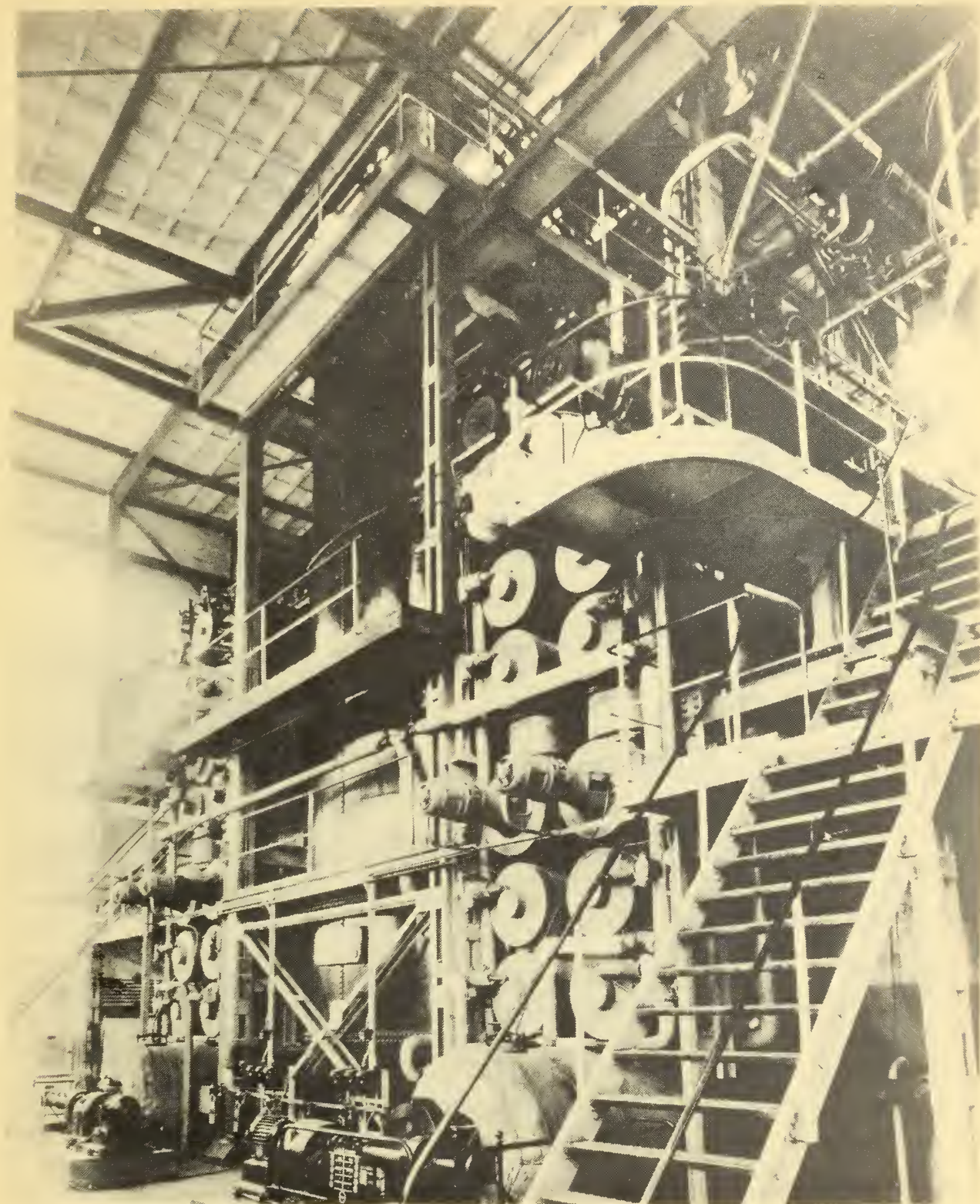


Figure 15.- An installation of the Bollman system of solvent extraction. (Courtesy of Albert H. Bruecke)

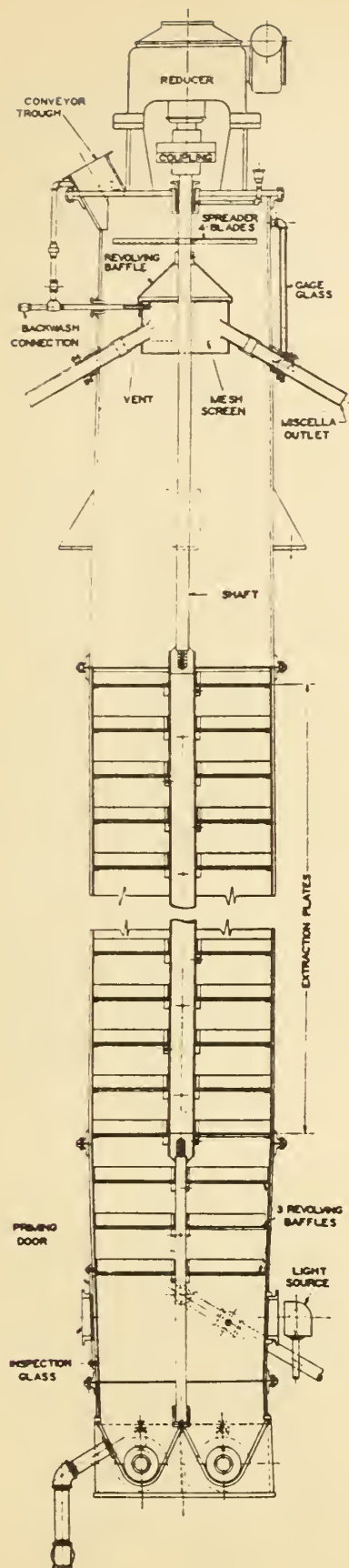


Figure 16.- The Allis Chalmers extractor.

contains a series of horizontal circular plates, equally spaced, and fixed to a central shaft which is slowly rotated by a gear-motor. The upper surface of each plate is wiped by a stationary scraper arm fastened to the inner wall of the cylinder. Slots are cut in the plates so that, during rotation, the stationary baffles sweep material resting upon the disks through the slots onto the plate immediately below. The slot arrangement is such that the material follows a helical path in progressing downward through the equipment.

Bean flakes are introduced at the top, and while being slowly propelled downward, they are countercurrently washed with solvent which is pumped into the bottom of the tower. A thick layer of fresh flakes is maintained on the top plate, providing a filter bed to retain the fines dislodged in the lower parts of the column. Miscella overflows through a screen near the top and is filtered, centrifuged, or allowed to settle in conical tanks before being fed to the evaporators. Spent meal is discharged at the base of the column by means of plug forming screw ejectors (44) which force the solids through cone-loaded orifices. The pressures developed by the revolving screws are so regulated that they form plugs sufficiently solid to prevent escape of the liquid contents of the column. Most of the solvent is also squeezed from the meal before final emergence so that a fairly dry product is delivered to the driers. Later designs of this extractor have replaced these devices with a totally enclosed conveyor which receives the flakes at the column base and bears them upward, outside the column proper, until they are above the solvent level (25). The upper portion, i.e., that part which is above the solvent level, serves as a drainage zone so that at the top of the conveyor fairly dry material is discharged to the meal driers.

Removal of most of the solvent from the oil (43) is accomplished in calandrias which feed into a flash chamber. The oil is then countercurrently scrubbed with saturated steam in a bubble cap tower, and if desired it is given a water-washing treatment to remove phosphatides. The Allis-Chalmers extractor has been built in sizes having capacities of 70 and 100 tons per day.

The Ford extraction system

The Ford Motor Company has developed a soybean extraction system with the original intention of providing an inexpensive and easily operated apparatus which could be adapted to community operation. The only installations, to date, have been made by the Ford Motor Company, primarily to provide oil for their automobile finishes (186); and it is intended that further research will lead to consumption of substantial quantities of the extracted meal within the Ford plant.

The complete system (113) is shown in Figure 17. The extractor itself is an inclined tube enclosing a ribbon or helical conveyor and provided with two vertical standpipes at the lower end, one for admission of fresh flakes and the other for miscella overflow. The flakes are carried upward against a counterflow of solvent which fills only a little over half of the tube.

The upper portion of the tube is steam-jacketed to effect preliminary solvent removal, and immediately below is another steam-jacketed drier section to complete the separation of last traces of solvent. The newer and larger installations have the latter meal drier built horizontally, on the floor beneath the extractor tube, and its length has been increased to permit any desired degree of toasting in the final product.

The miscella, containing 12 to 15 percent oil, flows through a heat exchanger and then to a still. The latter is a steam-jacketed pot whose exit vapors pass directly into the heat exchanger. In the steam jacket there is a spiral coil through which the miscella flows and from which it is discharged, at a temperature considerably above the boiling point of the solvent, to flash into the top of the still pot. The unevaporated portions run downward over baffles into the bottom of the pot and then pass to a packed column in which the crude oil is countercurrently scrubbed with steam. The amount and quality of the steam are controlled to bring about hydration of the phosphatides which are removed by allowing them to settle out in the storage tanks. The supernatant oil is practically free of "break" materials.

Ford installations employ the "horn-angle" type of flaking equipment (73) in place of the conventional single pair of rolls. As shown in Figure 18, a cylindrical roll revolves inside an annulus having an inner diameter slightly larger than the diameter of the smaller roll. Such an arrangement provides an exceedingly small angle of nip and correspondingly higher capacity for a given roll diameter. At one time, the Ford system used an extrusion flaker in which a continuously revolving feed screw compressed the soybeans and forced them through a narrow annular opening.

The Ford extractor has been built in many small sizes for demonstration purposes, but the units which are at present used to produce oil for the automobile factory are said to have daily capacities of 6 and 24 tons, respectively. Figure 19 is a photograph of the interior of the plant at Saline, Michigan, in which two of the 6-ton units are operated.

Other solvent systems.

The patent literature is profuse with descriptions of solvent extractors, many of which have been used at some time on various forms of oil seeds. Except for those already described, none is now being used commercially for processing soybeans in this country. There are a number of proposed systems, some used experimentally, which are available but have not yet been put into competitive operation.

A radical departure from present practice is incorporated in the extractor developed at Iowa State College by the R. and H. Chemicals Department of E. I. duPont de Nemours and Company. It has been placed on the market by the Detroit Rex Products Company. To avoid danger of explosion, trichloroethylene (ethylene trichloride, trichlorethylene) is used as a solvent in place of the highly inflammable hydrocarbons used in other equipment. The extractor itself resembles that of the Ford system in many respects, but since the solvent is heavier than the oil, the directions of flow of the solvent

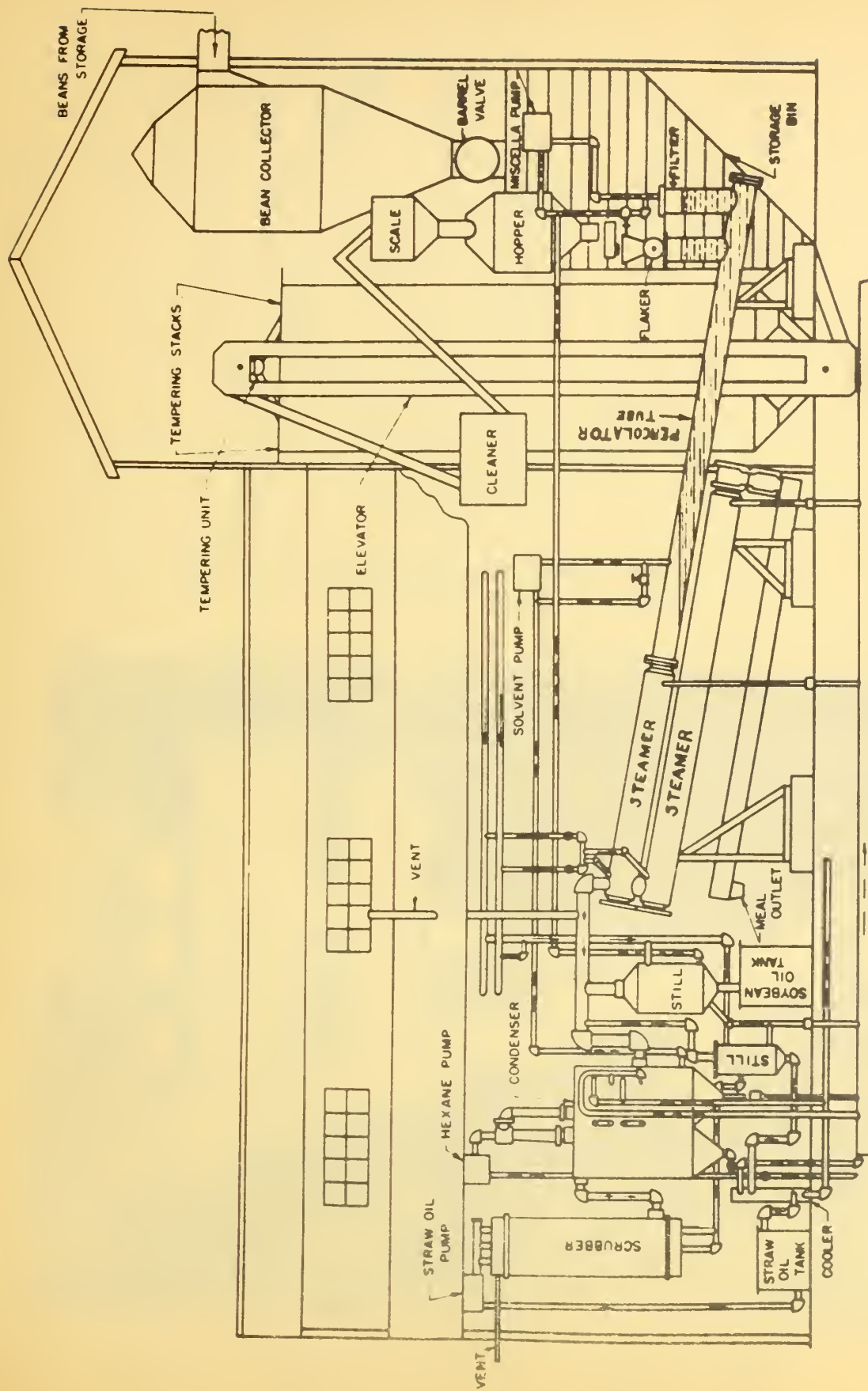


Figure 17.-- The Ford system of soybean extraction. (Courtesy of Ford Motor Company)

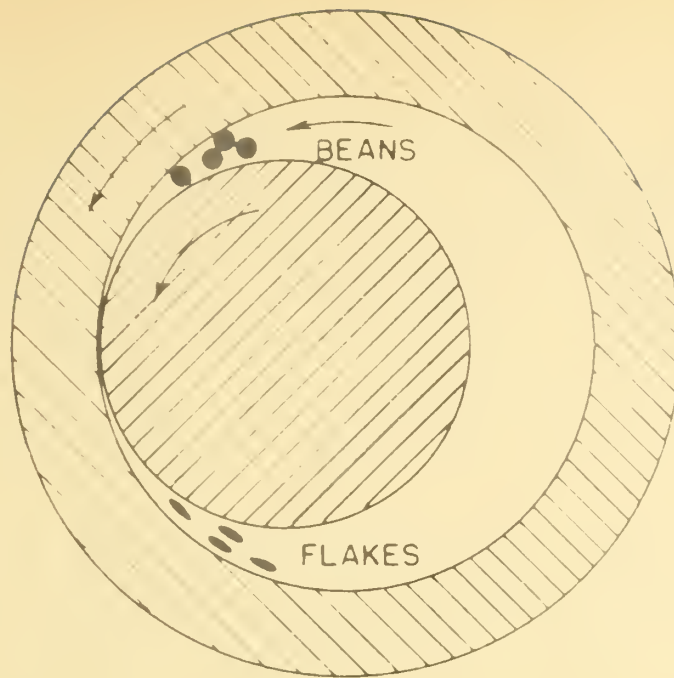


Figure 18.- The horn-angle flaking rolls used in the Ford extraction system.

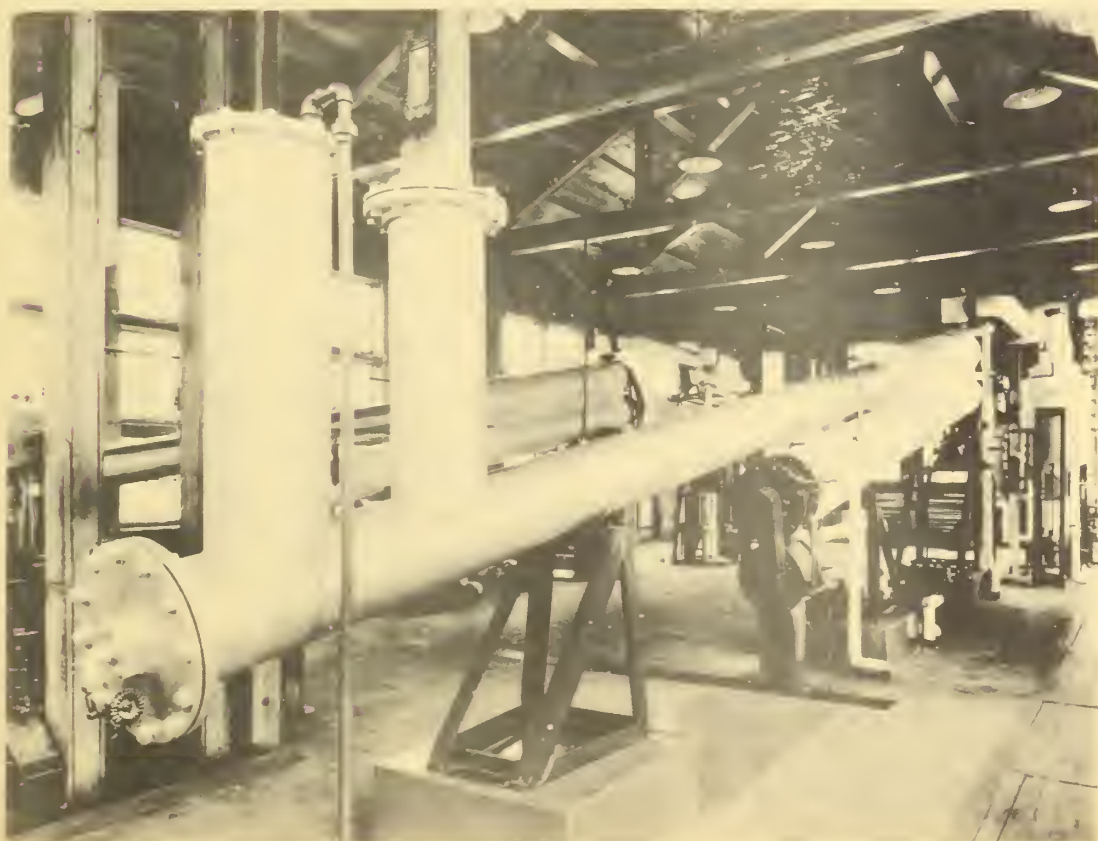


Figure 19.- Interior of Ford plant at Saline, Michigan, showing soybean oil extraction columns. (Courtesy of Ford Motor Company)

and the beans are reversed. The solids are propelled downward through the inclined tube, and at the lower end, a second screw conveyor then raises them in a short, nearly vertical standpipe to a level somewhat above that of the solvent, where they are discharged to the meal driers. Solvent is introduced into the standpipe and flows countercurrently downward, then upward through the inclined tube in which most of the extraction takes place. The rising concentration of oil in the trichloroethylene causes a gradual decrease in the specific gravity of the miscella and thereby minimizes the tendency for dissolved oil to be carried downward by the action of the helical conveyor. Experimental extraction is carried out in this apparatus using ground beans instead of flakes, and it is claimed that miscella handling difficulties due to suspended fines have been eliminated.

The bulk of the solvent is evaporated from the miscella in a steam-tube evaporator, and the residual solvent-containing oil is scrubbed with steam in a packed column. Since commercial grades of trichloroethylene boil at 86° to 88° C. compared with 63° to 70° C. for commercial hexanes, a somewhat more drastic treatment is necessary to accomplish a complete removal of the solvent. A modification of this type of extractor is described by Hamilton and Perkins (88).

A modification of the Kennedy extractor (115) is manufactured by the Wolf Company. In this system, a series of four-bladed paddle wheels takes the flakes from one to another of a series of rounded troughs placed side by side. A paddle wheel revolves in each depression and its blades closely fit the circular contour of the trough. The solvent flows countercurrently and passes through perforations in the blades. One of these extractors is now being used for the commercial production of cocoa butter.

The Böhm system (26) of extraction is manufactured by Otto Wilhelm, Stralsund, Germany. It consists of two adjacent vertical columns of rotating perforated plates spaced in staggered positions. The material to be extracted is charged onto the uppermost plate and the rotation causes it to be transferred, by means of a fixed scraper blade, to the next lower plate in the adjacent column. Here a similar operation discharges the solids onto a still lower plate in the first column. The procedure is repeated on each of the six plates until the spent flakes are discharged at the bottom. Countercurrent extraction is secured by spraying solvent or partial miscella over each plate, pure solvent being used for the bottom stage and nearly full miscella for the uppermost one. Between each step, the partial miscella is pumped to the next higher plate. The system is manufactured in sizes having daily capacities of from 30 to 200 metric tons of raw materials.

In the Fauth system (69, 70, 71, 79, 80), extraction is carried out on a series of vibrating screens, the material being pressed between hollow perforated rolls after each stage. There are approximately 6 of these units operating in Europe on a variety of oleaginous materials. The installations are said to have a capacity of 120 metric tons per day, each.

The Miag extractor, also German-built, is used in South America on a wide variety of oilseeds and presscakes. It consists of a large wheel, rotating in a vertical plane, having perforated compartments or "filter cells" on its periphery. An annular casing encloses the entire wheel in such a way that the "filter cells" continuously traverse a closed annulus, a stream of solvent being circulated in counterflow through the same annular raceway. The solid materials are introduced into the "filter cells" on the descending side at a level about even with the wheel shaft and are discharged after they have made three quarters of a revolution and are at the top of the wheel. The spent solids fall into a trough from which they are discharged by screw conveyors. The miscella leaves through a special strainer in the outside of the annular casing, the construction being such that the revolving wheel of "filter cells" provides continuous wiping action to prevent plugging the screen openings.

Solvents

So far as the authors are aware, there is only one extraction plant in the world now processing soybeans on a commercial scale with any other solvent than petroleum fractions. The single exception is a Manchurian plant using absolute alcohol. In this country, most of the solvent consists of hexanes, a typical commercial grade of which has a boiling range of 146° to 158° F. and a specific gravity of 0.685 at 60° F. It is so flammable that its use by any but experienced operators is hazardous, and modern extraction plants are accordingly designed to afford the greatest possible protection from explosions.

Buildings should be well ventilated and provided with large areas of windows designed to open or shatter easily in order to relieve pressure in the event of an explosion. The plant should be located at some distance from the power house, and no open lights, flames, etc., should be permitted in the vicinity. Only explosion proof motors and related equipment are permissible, and electric wiring must conform to requirements of the National Electrical Code. Only sparkproof tools should be used in the building, and floors and stairways should be of the grating type. Bonotto (40) describes in some detail the precautions which should be followed. A number of both major and minor solvent explosions have occurred, two of which are described by Price and Brown (148) and by Price (147).

An ideal solvent should, of course, be capable of penetrating the bean flakes and rapidly dissolving and removing the oil. Obviously, it must also be easily removable from the oil and the meal, leaving both products in satisfactory form for consumption. Other factors entering into the choice include cost, ease of recovery, fire and explosion hazard, corrosiveness, toxicity, and boiling range. The hexanes now commonly used possess most of the desirable characteristics, their only serious limitation being the extreme fire hazard.

Numerous solvents have been proposed and used experimentally in efforts to reduce the danger of extractor operation. Of these, the chlorinated hydrocarbons have received a great deal of attention, and as previously pointed out, trichloroethylene is employed in one of the systems now being offered

for sale. The use of trichloroethylene and similar solvents has been described by Hassel (93). A number of fluorinated hydrocarbons are also now commercially available, and except for their expense these appear to be desirable solvents.

The use of liquid propane, under pressure, has been proposed by Rosenthal and Trevithick (158, 159, 160). The same authors reported (161) experiments suggested by German Patent 163,057 claiming the use of liquid carbon dioxide as an extracting solvent. It was concluded that liquid carbon dioxide has no solvent power for cottonseed oil. Obviously, it would also be of no use for extracting soybean oil.

Attention has recently been focused upon the use of solvents which exhibit two-liquid immiscibility with soybean oil. One such solvent is ethyl alcohol which dissolves the oil completely at elevated temperatures but which displays only limited solubility at room temperature. Such solvents are of interest because of their ability, in some cases, to dissolve selectively the more highly unsaturated portions of the oil. The use of sulfur dioxide in this connection has been patented (61, 72, 85). In more recent patents, Freeman (74) claims the use of furfural and other liquids for the same purpose.

Hot alcohol extraction process

The extraction of soybeans by means of alcohol was intensively investigated by Sato and coworkers (162, 163, 164, 165), Okano and coworkers (141), Ohtomo (142), Mahino (132), Iwasa (133), and others (50, 110, 111, 112). Based principally on the results of the earlier studies, a plant was erected in Dairen by the Manchuria Soybean Industry Company for the alcoholic extraction of soybean oil and meal.

When soybean oil is dissolved in absolute ethyl alcohol at temperatures higher than about 150° F., a homogeneous solution is obtained. Upon cooling, two layers form, a lower one consisting chiefly of soybean oil with a small amount of alcohol and an upper layer which is mainly alcohol containing a small amount of oil. The relative amounts of the two layers and their compositions depend upon the original solvent-oil ratio, the proof of the alcohol, and the temperature.

The plant at Dairen has a daily capacity of approximately 100 tons of beans which are processed in a battery of rotary extractors. The solvent is 99.8-percent ethyl alcohol which is dehydrated at the plant. The beans are selected, cleaned, and if necessary they are warmed to a temperature of 85° to 105° F. before flaking. Since absolute ethyl alcohol is a dehydrating agent and loses its solvent power toward soybean oil in the presence of water, the flaked beans are dried to a moisture content of 3 percent. They are then charged into the extraction battery and leached with the alcohol at a temperature of 175° to 180° F., under pressure.

The resulting miscella is cooled to about 75° F. and pumped into a conical separating tank where oil containing 5 percent alcohol collects in the bottom. It is drawn off, and the solvent is removed in an evaporator.

The recovered oil is of semi-refined quality, having a light yellow color (30Y, 3R, 25 mm. cell), and an acid number of 0.14 to 0.20. It has a salty taste and can be used for edible purposes without further refining, although it is ordinarily further treated with fuller's earth and deodorized under vacuum.

The supernatant alcohol in the settling cone is returned to the extraction system, or when it becomes too contaminated with water or non-oil extractables, it is transferred to a still for recovery of the byproducts and subsequent rectification of the alcohol. During the evaporation in the still, sugars crystallize out, and by adding sulfuric acid it is possible to recover saponins. Finally, phosphatides are salted out, 55 to 60 percent pure. The residual meal contains 0.5 to 1.0 percent oil and requires no refining for use in foodstuffs such as "misq" "shoyu," "ajinomoto," etc. It reportedly commands a price 25 percent higher than meal produced by other methods.

The principal advantage of the alcohol extraction method is the ease of byproduct recovery. However, the American market for the above-named byproducts is not highly developed and there has therefore been little incentive toward the introduction of the process into this country. The cost of alcohol relative to that of hydrocarbons, the relatively high latent heat of evaporation of ethyl alcohol, and the high initial cost of the equipment are additional deterrents.

Extractor design data

The literature contains practically no data on the rates of extraction of soybean oil under various conditions, on the concentration of miscellas in equilibrium with partially extracted beans, on the diffusivity of soybean oil in various solvents under various conditions, etc. In other words, extractor design is now based almost entirely upon experience rather than upon any mathematical analyses of the processes taking place in the equipment. Many methods of approach to an analytical solution to problems in continuous extraction have been suggested. Among them, the solutions of Elgin (64) and Ravenscroft (149) are worthy of note. A simplified analysis as well as a detailed description of extraction of many types of solid materials is given by Donald (57).

6. Hydraulic pressing.

Hydraulic presses or their more primitive hand- or animal-powered counterparts are used almost entirely by the Manchurian soybean oil industry (12).

In the more remote interior districts of that country, some small mills still employ presses which are actuated by hand-driven wedges. The beans are first crushed into wafers beneath a large granite millstone, as shown in Figure 20, and then placed in coarse sacks over a wooden grating which is laid upon pots of boiling water and steamed for about 15 minutes. The



Figure 20.- Crushing soybeans preparatory to steaming and pressing for oil in a primitive type of mill. On the left is a vat over which the crushed beans are steamed before they are placed in the oil press. (Courtesy of W. J. Morse)

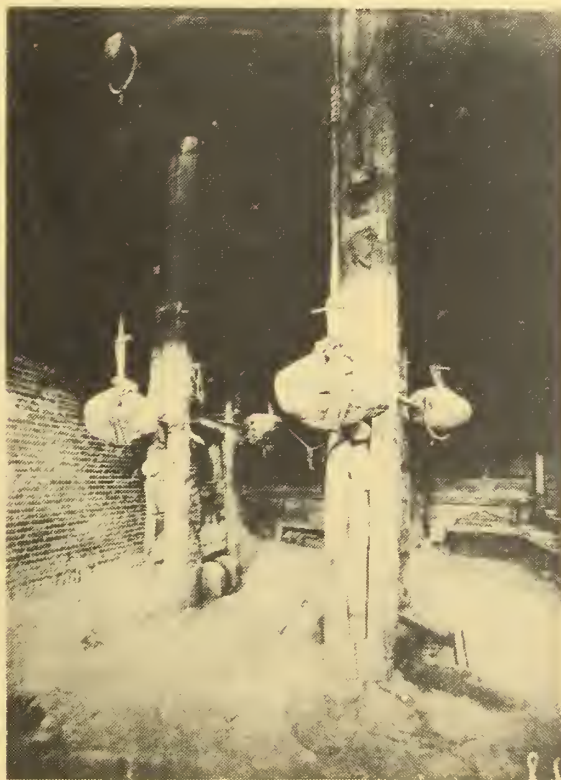


Figure 21.- Old wedge Chinese oil presses used in remote villages of Manchuria. (Courtesy of W. J. Morse)

resultant mass is spread out in circular frames about 6 inches deep. Five of these frames are placed one above another in a vertical press consisting of four upright posts with cross-beams at the top and bottom. Pressure is applied by means of wedges driven between the cross-beams and beams placed on top of the frames, and the oil is thus expressed. One of these primitive installations is shown in Figure 21.

The wedge press is one of three general types which produce so-called "round cakes." Most Manchurian mills employ the "screw system" in which hand-powered screws replace the wedges. Most of the operations, with the exception of the actual pressing, are more or less mechanized in the mills using this method. In the majority of the very large mills, particularly in the oil producing centers such as Dairen, the screw system has been replaced by the hydraulic "round cake" process in which the screws are replaced by hydraulically operated rams. A few of the most modern mills employ the "plate cake" system which produces a flat rectangular cake and which is essentially the same as the hydraulic methods used in the United States. An installation of round cake screw type presses is shown in Figure 22.

The American soybean industry has, for the most part, abandoned hydraulic pressing because of the relatively higher labor costs. There are, however, a considerable number of cottonseed mills and some linseed oil mills which use their equipment wholly or in part to crush soybeans. Since cottonseed processing is considered to be much more seasonal than that of soybeans, many mills run on soybeans after the cottonseed crop has been consumed. The operations of a hydraulic mill require only slight modification in order to handle soybeans.

With soybeans, the steps of delinting and dehulling, as employed on cottonseed, are omitted. Beans are cleaned, weighed, and adjusted to a moisture content of approximately 12 percent. They are then cracked by means of a disc huller or attrition mill and rolled into flakes by means of the usual 5-high crushing rolls which are universally used in hydraulic cottonseed oil mills.

The operation of a set of these rolls is illustrated diagrammatically in Figure 23. The five cylindrical rolls rest upon one another, and the bearings upon which they rotate are free to move up or down. The cracked material is fed at the top, and a series of scraper guides and cant boards is so arranged on the rolls that the material passes downward between successive pairs of rolls in serpentine fashion. The pressure exerted on the beans during any particular pass is caused by the combined weights of the rolls above and therefore increases with each pass. The final product resembles irregularly shaped fragments of paper 0.007 to 0.008 inch thick. The purpose of this operation is to rupture as many as possible of the cell walls in order to facilitate subsequent release of the oil.

The flaked beans are conveyed to a cooker, the usual type being the "stack cooker" commonly used in many types of oilseed milling. Figure 24 shows a phantom view of one of these machines. It consists of several (usually 4 to 6) steam-jacketed, cylindrical kettles, stacked one above the other. A rotating central shaft extends vertically through all the compartments

and has scraper arms attached. The shaft and arms carry ports to permit admission of moisture. Steam-jackets are provided not only on the sides, but also between the compartments, and the separate kettles are connected by damper-controlled doors which permit the charge to fall from one pan to another. The bean flakes are admitted at the top and work downward through the separate compartments, emerging from the lowest in a thoroughly cooked condition. The flakes are moistened to 12 to 15 percent moisture content before admission to the cooker, and during the cooking process which lasts 70 to 90 minutes, the moisture content is reduced to 6 to 8 percent. Although a higher moisture content tends to release the oil somewhat more easily, it imparts too soft a consistency to the cooked material for efficient pressing and results in rapid destruction of press cloths.

The cooker discharges into a hydraulically operated cake former which molds the hot material into a slab about 2 inches thick, 14 inches wide, and 3 feet long, and wraps it in a thick cloth made of human hair or a special grade of wool. A typical cake former is shown in Figure 25. The cakes are placed into the boxes or between the plates of a hydraulic press, each press having approximately 15 boxes or plates. A complete box type of press is shown in Figure 26. Figure 27 is a closer view of several press boxes. Boxes are used in mills which normally process cottonseed, and the plate type of press is found mainly in linseed mills. In the latter type, the plates have heavy rope mats on their surfaces. The cakes, encased in press cloths, are placed between the heavy mats on the plates. Pressure is applied to the cakes, and when the pressure of the oil in the hydraulic cylinder reaches 500 pounds an automatic change valve switches the system to a high pressure pump. The ultimate pressure used is 4,000 to 4,500 pounds per square inch on a 16-inch-diameter ram and amounts to about 1,600 pounds per square inch at the cake. The pressing cycle consists of (1) drainage period of 15 to 30 minutes and (2) emptying and refilling the press, the latter operations requiring 8 to 10 minutes in all.

The pressed cakes, still wrapped in the press cloths, are run through a cloth stripper, and the cloths are reused. The pressed slabs are passed through a cake trimmer which removes the less-thoroughly pressed edges to be re-processed. The slabs of cake are fed to a cake breaker and then ground into meal in an attrition mill.

Cage presses, too, are used to a small extent on soybeans. Each press consists of a vertical cylindrical pressing cage, composed of closely spaced steel bars or slotted steel plates, into which a hydraulic ram is forced from below. The cages are filled with loose bean flakes from the top, as delivered from the cooker, a heavy cover is locked into place and pressure is applied to the ram. After the drainage period, the cover is removed and the ram is further raised to discharge the press. It is customary to employ several cages, all fed from the same cooker. The cage type of press is used in mills which process special materials or a wide variety of oilseeds because it develops much higher unit pressures on the oil-bearing material than can be realized in either the box or plate type of presses.

In a hydraulic press room a great deal of manual labor is required for operating the cake former, carrying cakes from the former to the presses

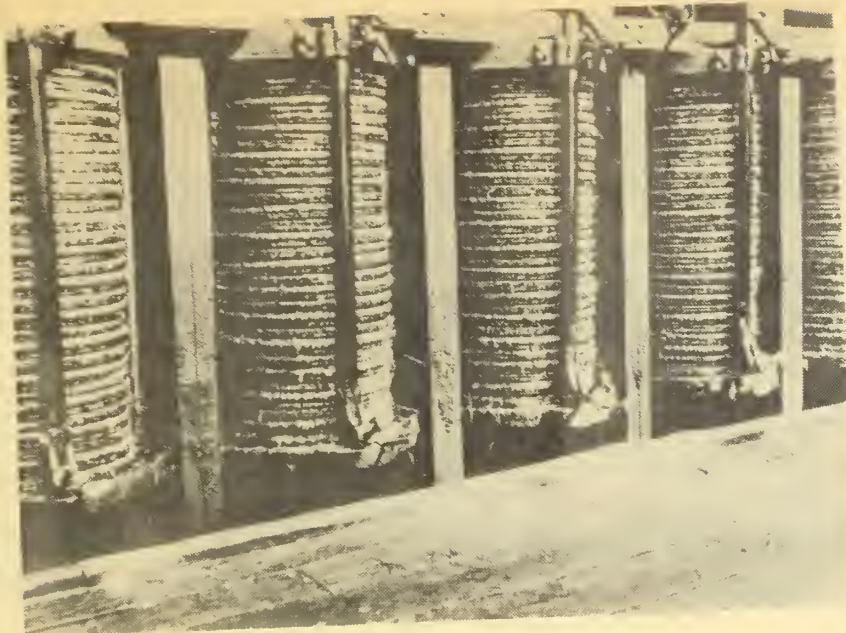


Figure 22.- Screw presses in a soybean oil mill in Dairen, Manchukuo. (Courtesy of W. J. Morse)

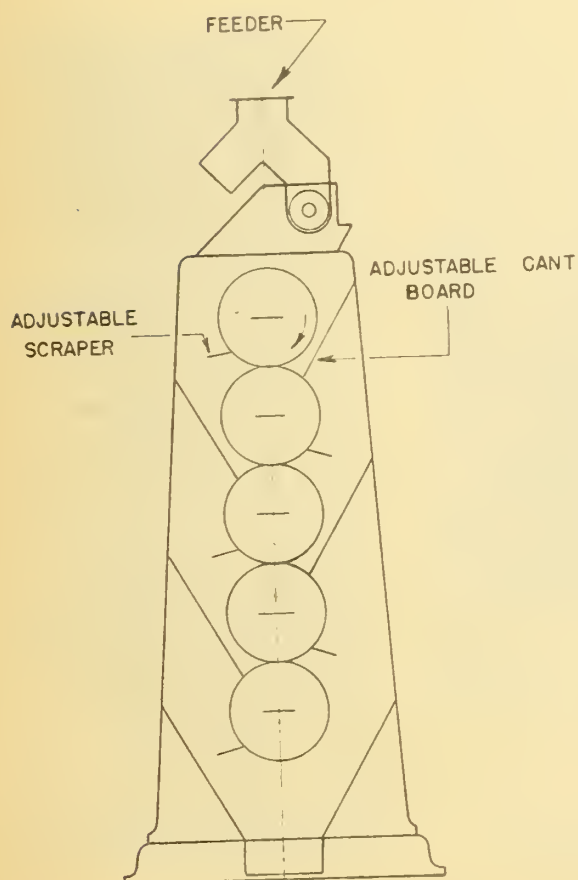


Figure 23.- Five-high flaking rolls of the type used to prepare soybeans, cottonseed, and other oilseeds for hydraulic crushing. Sectional view.

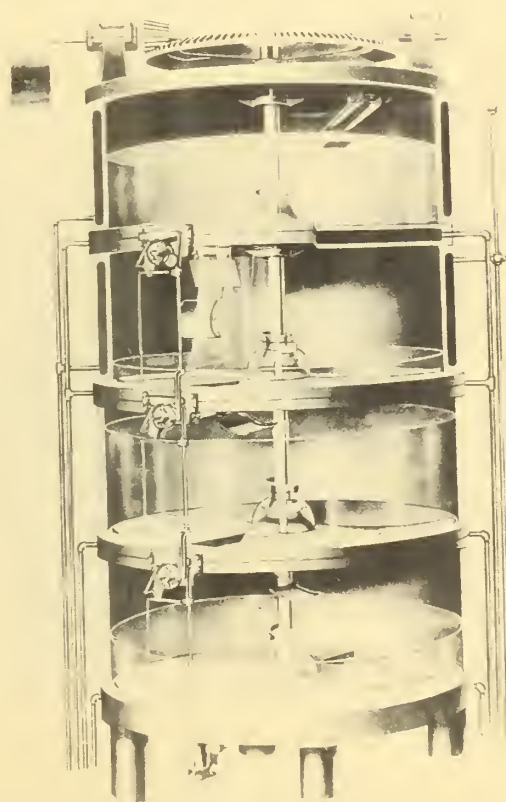


Figure 24.- Phantom view of stack cooker used to prepare material for hydraulic pressing and for toasting solvent-extracted soybean flakes. (Courtesy of French Oil Mill Machinery Company)

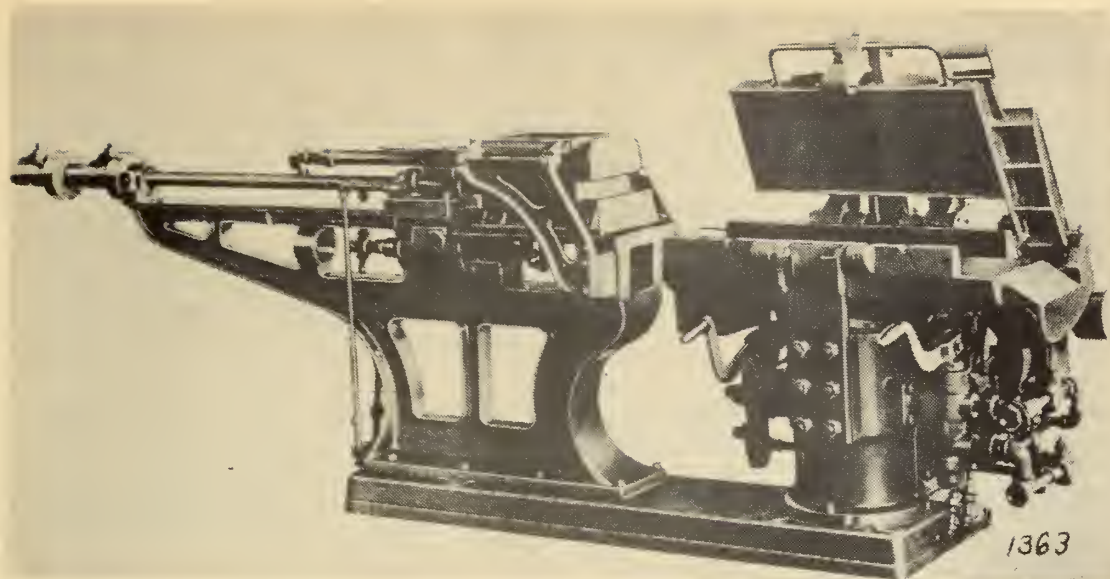


Figure 25.- Cake former in which cooked soybean flakes are molded into flat cakes and wrapped in cloths, preparatory to hydraulic pressing. (Courtesy of French Oil Machinery Company)

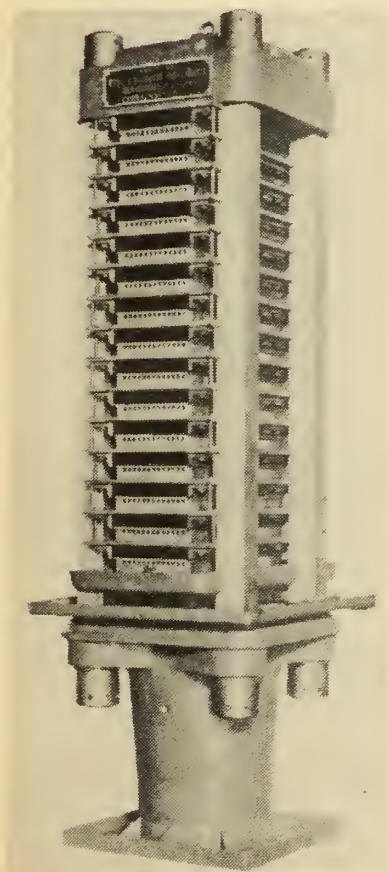


Figure 26.- A hydraulic press. (Courtesy of French Oil Mill Machinery Company)

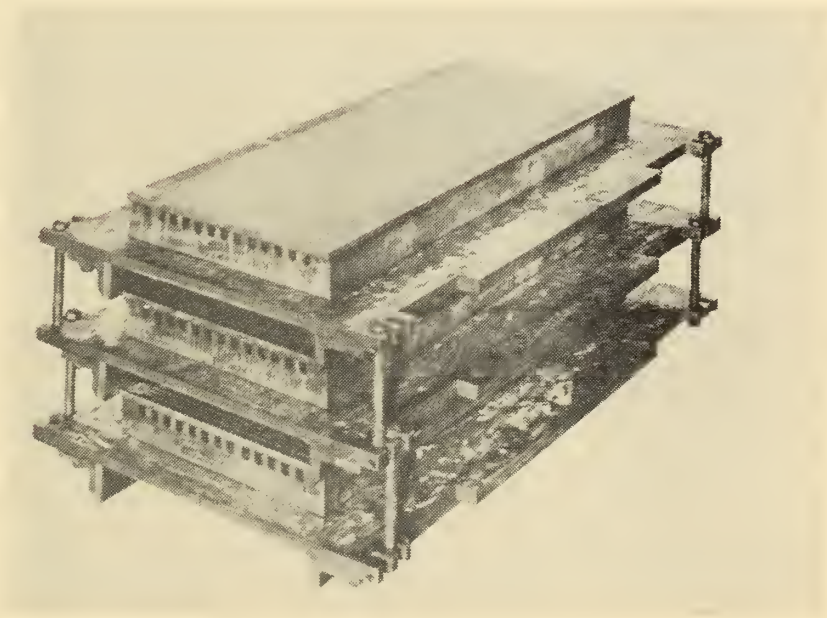


Figure 27.- Hydraulic press boxes. (Courtesy of French Oil Mill Machinery Company)

and from the presses to the cloth stripper, loosening pressed cakes from the press boxes or plates, and operation of the cloth stripper and cake trimmer. In the more modern continuous press installations and solvent extraction plants the amount of hand labor is reduced to a minimum and the operating costs appear to be correspondingly lower. It is for this reason that there are few, if any, hydraulic mills crushing soybeans in the United States except those which were originally built for processing other seeds, notably flaxseed and cottonseed.

Some observations of the effects of pressure, temperature, and time of pressing upon the rate of removal of oil from soybeans have been reported by Koo (119) who has also reported similar data for cottonseed and tung nuts (118, 120).

7. Miscellaneous processing methods

A process for removing oil from oil bearing seeds by bacterial action has been patented and described by Beckman (23, 24). The seeds are ground and mixed with water to produce a mush. Calcium carbonate is added to maintain a near-neutral pH, and the mixture is inoculated with Pacillus delbrueckia which is obtained from brewers malt. The mixture is allowed to stand for 5 or 6 days at 50° C. while the organism attacks the sugars and produces lactic acid from them. The oil is released and floats to the surface. Although fair yields are obtained with copra and a few other oleaginous materials, Horovitz-Vlassova and Novotelnov (106, 107) report that they were unable to make the process work on soybeans, cottonseed, linseed, corn germs, and similar materials. The latter authors ascribe the release of the oil to the penetration of lactic acid into the cells whereas Beckman attributes it to the action of enzymes which are produced simultaneously with the lactic acid and which attack the proteins, degrading them into amino acids.

David and Felizat (52) have patented a method for extracting oil by beating the finely ground oilseeds with water and floating out the oil. In their process, the comminuted materials are mixed with an alkaline solution, and the cellulosic constituents of the resulting slurry are removed by successive washings on a screen. The filtrate contains starch granules (if the particular oilseeds contain starch) in suspension, proteins in a peptized form, and emulsified oil. The starch is separated by a relatively mild centrifugal treatment, and the oil is then removed in high-speed centrifuges. The protein is recovered by acid precipitation.

The use of a pulp beater for a similar purpose has been described by Freise (75). In his experiments, a yield of 95 percent of the oil contained in soybeans was obtained by feeding them at 40° C. through an experimental beater at a density of 5 to 8 percent. The power consumption was less than 2 kilowatt hours per bushel and the filtered oil was said to be of good quality.

8. Soy flour

Considerable quantities of soy flour are produced by milling whole soybeans or the oil-free meal. The annual United States production has been approximately 25,000,000 pounds in recent years. It is used principally in the manufacture of sausage, dog food, miscellaneous meat products, and in bakery goods. In the production of bread, it is admixed with wheat flours in various proportions.

In the manufacture of soybean flour it is necessary to remove the hulls, and this can be accomplished by subjecting cracked soybeans to an aspirating or a centrifugal treatment. It is also necessary to remove the beany flavor generally associated with ground soybeans. Several "debittering" processes are referred to by LeClerc 8/. For the most part, they comprise treatment with heat, steam, or inert gases at elevated temperatures, often under vacuum or in the presence of an inert protective coating of oil.

9. Cost of processing soybeans

No attempt will be made in this discussion to furnish costs of erecting and operating soybean mills since information on this subject can more adequately be furnished by equipment manufacturers. Data on the items of expense incident to soybean crushing have been published by Sweeney and Arnold (185), and by Torri (191), as well as in various trade journals (15, 21). However, what appear to be more accurate figures for the bare costs of installing and operating both solvent and continuous press types of mills have more recently been tabulated by Bilbe (25). In addition, the trade journals have published a number of descriptions of modern soybean mills (13, 16, 19, 20).

For the convenience of those interested, Table 3 is appended listing a number of manufacturers of soybean processing equipment. It is to be understood that the products of these manufacturers are not recommended more highly than those of other manufacturers who might be in the same business. No discrimination is intended nor is any guarantee of completeness implied. (See page 31 for Table 3). It must be realized that such a list is subject to continual change, however.

8/ LeClerc, J. A. Partial list of processes for removing the bitter taste from soybeans. U. S. Dept. of Agriculture, Bur. of Chemistry and Soils, Food Research Division, 1 p. October 11, 1938. (Mimeographed.)

Table 3. Manufacturers of soybean processing equipment

Continuous presses:

V. D. Anderson Company, Cleveland, Ohio
French Oil Mill Machinery Company, Piqua, Ohio

Hydraulic pressing equipment:

French Oil Mill Machinery Company, Piqua, Ohio
Davidson-Kennedy Company, Atlanta, Georgia
Buckeye Iron and Brass Works, Dayton, Ohio

Continuous countercurrent solvent extractors:

Vulcan Copper and Supply Company, Cincinnati, Ohio
French Oil Mill Machinery Company, Piqua, Ohio
Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin
Albert H. Bruecke (Bollmann system), 10 Carlisle Street,
Bergenfield, New Jersey
Sieck and Drucker, Inc. (Hildebrandt system), 9 South Clinton
Street, Chicago, Illinois
Detroit Rex Products Company, 13005 Hillview Avenue, Detroit,
Michigan
The Wolf Company, Chambersburg, Pennsylvania

Milling equipment:

Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin
B. F. Gump Company, 441 South Clinton Street, Chicago,
Illinois
Great Western Manufacturing Company, Leavenworth, Kansas

Mill construction contractors:

Newell Construction and Machinery Company, Cedar Rapids, Iowa

In Table 4 on page 32, there are listed those oil mills in the United States and Canada which may be classified as full- or part-time soybean mills.

Table 4. Soybean processing mills

Mills are listed below which process soybeans or are reported to be equipped or will be equipped for soybean crushing. This list is furnished for the information and assistance of the public, but it is to be understood that no guarantee of accuracy or completeness is implied nor is any discrimination intended.

United States

Arkansas:

Little Rock: Rose City Cotton Oil Company
Osceola: Ralston Purina Company
Prescott: Nevada County Oil Mill
Wilson: Wilson Seed and Feed Company

California:

Oakland: Albers Brothers Milling Company

Colorado:

Denver: Dawe's Products Company
Greeley: Soy Bean Products Company

Illinois:

Bloomington: Funk Brothers Seed Company
Cairo: Cairo Meal and Cake Company
Swift and Company
Champaign: Swift and Company
Chicago: Archer-Daniels-Midland Company
The Glidden Company
Norris Grain Company
Spencer Kellogg and Sons
Decatur: Archer-Daniels-Midland Company
Decatur Soy Products Company
Spencer Kellogg and Sons
A. F. Staley Manufacturing Company
Galesburg: Galesburg Soy Products Company
Gibson City: Central Soya Company, Inc.
Monmouth: Ralph Wells and Company
Peoria: Allied Mills, Inc.
Quincy: Quincy Soybean Products Company
Springfield: Illinois Soy Products Company
Taylorville: Allied Mills, Inc.

Indiana:

Decatur: Central Soya Company, Inc.
Indianapolis: Evans Milling Company
Lafayette: Ralston Purina Company
Marion: Hoosier Soybean Mills, Inc.
Windfall: Elevators and Mills, Inc.

Iowa:

Cedar Rapids: Honeymead Products Company
Iowa Milling Company
Centerville: Standard Soybean Mills
Clinton: The Clinton Company
Des Moines: Spencer Kellogg and Sons
Swift and Company
Fayette: Wilbur Bell, Inc.
Fort Dodge: Plymouth Processing Mills
Iowa Falls: Ralston Purina Company
Quimby: Simonsen Soybean Mill
Waterloo: Soy Bean Processing Company

Kansas:

Emporia: Kansas Soy Bean Mills, Inc.
Kansas City: Kansas City Soybean Mills
Fredonia: Archer-Daniels-Midland Company

Kentucky:

Louisville: Buckeye Cotton Oil Company
Owensboro: Owensboro Grain Company
Henderson: Ohio Valley Soybean Cooperative Association

Louisiana:

Alexandria: Independent Mill and Gin Company
Ville Platte: Evangeline Cotton Oil Company

Michigan:

Dearborn: Ford Motor Company
Milan: Ford Motor Company
Saline: Ford Motor Company

Minnesota:

Mankato: Mankato Soya Products Company
Minneapolis: Archer-Daniels-Midland Company
Blooming Prairie: Blooming Prairie Farmers Cooperative
Elevator Association

Mississippi:

Port Gibson: Port Gibson Oil Works

Missouri:

Oronogo: Spring River Mill
St. Joseph: Danner Grain and Milling Company
St. Louis: Ralston Purina Company

Nebraska:

Fremont: Pete Farr Processing Company
Omaha: Allied Mills, Inc.

New York:

Buffalo: Archer-Daniels-Midland Company
Spencer Kellogg and Sons
Oswego: Oswego Soybean Products Corporation

North Carolina:

Benson: Benson Oil Mill
Clayton: Central Oil and Milling Company
Farmville: Farmville Oil and Fertilizer Company
Fayetteville: Southern Cotton Oil Company
Fremont: Fremont Oil Mill Company
Goldsboro: Southern Cotton Oil Company
Hertford: Southern Cotton Oil Company
Kinston: Lenoir and Ice Company
New Bern: New Bern Cotton Oil and Fertilizer
Mills
Raleigh: Buckeye Cotton Oil Company
Sanford: Sapona Mills
Tarboro: Southern Cotton Oil Company

Ohio:

Berea: Berea Milling Company
Cincinnati: The Drackett Company
Circleville: John W. Eshelman and Sons
Ralston Purina Company
Fostoria: Swift and Company
Marion: Old Fort Mills, Inc.
New Washington: Ohio Soya Company
Painesville: A. E. Staley Manufacturing
Company
Toledo: Archer-Daniels-Midland Company
Toledo Soybean Products Company
Wooster: Soya Processing Company

Oklahoma:

Oklahoma City: Terminal Oil Mill Company

Pennsylvania:

Jersey Shore: Pennsylvania Soy Bean
Cooperative Association

Tennessee:

Memphis: Buckeye Cotton Oil Company
Nashville: Nashville Cotton Oil Mill

Virginia:

Norfolk: Davis Milling Company
Portsmouth: Allied Mills, Inc.
I. F. Laucks, Inc.

Wisconsin:

Milwaukee: Archer-Daniels-Midland Company
New Richmond: Doughboy Mills, Inc.

Canada

Ontario:

Paden: Dominion Linseed Oil Company
Owen Sound: Dominion Linseed Oil Company
Toronto: Toronto Elevators, Ltd.

Production and Refining of Phosphatides

Prepared by Klare S. Markley

The industrial production of soybean phosphatides on a large scale has been a relatively recent development which resulted primarily from the introduction and general processing of Manchurian soybeans by German oil mills during the 1920's, and as a further consequence of which the process and apparatus have been largely developed in Germany.

Since about 1900 many patents have been granted, especially in Germany, covering the recovery and purification of phosphatides from various plant materials, and particularly from oilseeds and oil bearing materials. The raw materials have comprised wheat, corn, rye, and barley germs (207), and lupins (49), peas (99), soybeans, and other legumes. Ethyl and methyl alcohol were principally employed as solvents, and acetone and salt solutions as purification agents.

With the development of solvent extraction methods in Germany for the production of soybean oil, the industry was confronted with the problem of disposing of the sludge which separated from the oil when it was clarified by settling or other means. This sludge or foots comprised an emulsion of phosphatides, phytins, bitter principles (glucosides), sterols, mucilaginous substances, finely divided meal, water, and oil. Relatively large volumes of this sludge or foots accumulated at the oil mills. This disagreeable, malodorous mass soon underwent decomposition with the formation of even more disagreeable odors, and its disposition became a serious problem to the industry.

Two groups of patents each covering different processes for the recovery of phosphatides and oil from these sludges or foots were granted about the same time to the firm of J. D. Riedel Akt.-Ges. and to the Hanseatische Mühlenwerke Akt.-Ges., respectively.

The process covered by the patents of the J. D. Riedel Akt.-Ges. (153, 154, 155, 156), was based primarily on the use of organic solvents for the extraction and purification of the phosphatides contained in the byproduct sludges produced during the refining of soybean oil. It consisted of a series of steps wherein dehydration of the sludge in a vacuum at 40° to 50° C. was followed by extraction and separation of the phosphatides and oil by means of methyl alcohol and acetone. A variation of the method comprised the following successive steps: extraction of the sludge with alcohol to remove the water, oil, and phosphatides; separation of the solvent and water by distillation of the extract; and removal of the oil and bitter principles from the phosphatide residue by washing it with acetone. In this method the alcohol-insoluble phosphatides still remained in the residual sludge. In order to recover the alcohol-insoluble phosphatides, the sludge was re-extracted with benzene and the benzene extract treated with alcohol to precipitate the dissolved phosphatides.

The process never attained permanent industrial importance because of the development at about the same time of another process which was simpler, more efficient, and cheaper of operation. This second process which was known as the "Pollmann Process" (32) soon assumed dominant importance in the industry and remains so at the present time. It obviates the use of solvents. The principal steps of the operation comprise removal of the solvent by distillation of the miscella, heating the residual oil and treating it, with wet steam at 103° C. After about 15 minutes the phosphatides begin to separate as a flocculent mass containing oil and associated impurities.

The production and purification of soybean phosphatides has undergone various modifications and improvements since the process was first disclosed in the patent and scientific literature. In the original process the solvent mixture used for extracting the oil consisted of alcohol and benzene (31), although the use of other solvents was claimed. Subsequent steps in the purification of the recovered phosphatides were described in later patents (33, 35, 36, 151).

Because of the constant improvements which were introduced in the industrial processing of phosphatides, and the consequent flow of patents pertaining thereto, the descriptions of the process which are found in the technical literature vary somewhat in detail, and are not always in accord with the practice actually followed at the time they were written.

Grün (167), for example, described the process as operated about 1935 at the plant of the Hanseatische Mühlenwerke Akt.-Ges. in Hamburg somewhat as follows:

Soybeans are extracted in a Bollmann extractor with benzene, petroleum ether, or a mixture of the two, to which a little or as much as 30 percent of alcohol has been added. The solvent is removed from the miscella by distillation and the last traces removed by steaming. Additional water, usually in the form of steam, is admitted to the oil until precipitation of the phosphatides is complete, after which they are separated from the oil by centrifuging. The separated phosphatides are transferred to distillation apparatus, with the possible addition of more water, and the water and odorous impurities removed by distillation under vacuum at about 60° C. The distillation is continued until the residual phosphatides are freed from odor and flavor (34). The product thus obtained contains 60 to 65 percent of phosphatides. It is a brownish yellow product of good odor and flavor. The Hansa-Mühle plant in Hamburg is said to have a daily capacity for the production of phosphatides from 1000 metric tons (25,000 to 40,000 bushels) of soybeans.

A somewhat similar description of the production of phosphatides is given by Horvath (108).

Eichberg (63) gives a description of the process for the production of phosphatides which is more nearly in accord with present practices both in the United States and abroad. According to Eichberg and the patents cited by him the process followed at present (1939) is as follows:

A single petroleum hydrocarbon solvent is used in the extraction of the oil from soybeans which contain 1.5 to 3.0 phosphatides. The use of the single solvent does not remove all of the phosphatides from the beans, since the meal is found to contain about 1.0 percent of residual phosphatides. However, the use of a single solvent yields a product which is relatively free of carbohydrates and entirely free of bitter substances, the presence of which, according to Sorensen and Bean (182), results from the use of alcohol in the extraction process.

The oil containing the dissolved phosphatides is agitated with water at about 75 to 80° C. in order to flocculate the phosphatide emulsion, which operation requires about three quarters of an hour. The flocculent emulsion is separated from the oil by centrifuging and the separated phosphatides, which actually consist of an emulsion of phosphatides, oil, and water, are subjected to vacuum distillation to remove the water and volatile odor and flavor constituents (35). Simultaneously, they may be bleached with hydrogen peroxide (36), or preferably dibenzoyl peroxide (90), when it is desired to produce a light colored product for certain special uses. The product thus obtained, which consists of a mixture of about 60 to 65 percent phosphatides and 35 to 40 percent soybean oil, is used without further treatment in a variety of products.

However, for use in certain products, and especially for use in the pharmaceutical and chocolate coating industry, further treatment is necessary. This treatment usually consists simply of removing the soybean oil, or of removing the soybean oil and replacing it with another fat or oil. In order to accomplish this operation, the bleached and dried phosphatide-oil mixture is agitated with acetone, in which the oil is soluble. The supernatant liquid consisting of a solution of oil in the acetone is drawn off from the undissolved phosphatides and the acetone recovered by distillation (89). The acetone-treated phosphatides are again treated under vacuum to remove the last traces of acetone and the oil-free product marketed for use in the pharmaceutical industry, or further treated for use in the chocolate coating industry. For the latter use the product remaining after the removal of the bulk of the solvent, but prior to its complete removal by heating under vacuum (151), is mixed with another oil, such as refined peanut oil, coconut oil, cocoa butter, or hydrogenated oils. The mixture of phosphatides and added oil is then subjected to vacuum and heat to remove the last traces of solvent. The finished product finds wide use in the preparation of chocolate coatings. The total production and consumption of soybean phosphatides in the United States and abroad is unknown but a conservative estimate would be in the vicinity of ten thousand tons annually.

Various other processes have been proposed for the production and purification of phosphatides but most of them have not found any appreciable industrial application. Among these other processes may be mentioned the cold solvent extraction proposed by Rewald (150), which has for its object not only the recovery of undenatured phosphatides but also the production of soybean meal with a minimum of denaturation of the proteins. Gensecke (78) proposed the use of acidified saline solutions for removing the phosphatides from the oil. Melin and Tauboeck (117) proposed the use of silicic gels and similar oxidic sols to recover phosphatides from the solvent used to extract

the dehydrated crude phosphatides. Gehrke (77) proposed the use of dehydration by means of glycerine instead of vacuum distillation for the separation of water from the crude phosphatides. The process of dehydration with glycerine or concentrated aqueous sugar solutions has been patented by the firm of Noble and Thörl (137, 138, 139). Schwieger (173) proposed a method for purifying crude soybean phosphatides which comprises extracting the sludge with a solvent to remove the oil, treating the residue containing some residual solvent with water, evaporating the water and residual solvent, and incorporating another carrier such as a carbohydrate in an aqueous solution. Other processes pertaining to the separation of soybean oil phosphatides have been patented by Ginn (82), Kraybill (122), Thurman (187, 188, 189), Beck and Klein (22), and others. None of them are used commercially.

Processing soybean oil for food uses

Soybean oil as produced by the various processes of pressing and solvent extraction contains variable quantities of free fatty acids, coloring matter, phosphatides, albuminous or mucilaginous substances, aldehydic, ketonic, and other odorous constituents which render it unsuited in the crude state for many purposes. It is necessary, therefore, to subject the oil to various refining operations for the reduction, or more or less complete removal, of these objectionable products. Since soybean oil, unlike most vegetable oils, finds use in both the edible and the drying oil fields, the necessary degree of refining may depend on the ultimate use to which it is destined. For use in the paint industry, it may be subjected to so-called mechanical refining only; whereas for use in varnishes and enamels, it is ordinarily alkali-refined in a manner similar to that employed for the production of an edible oil.

When mechanically refined for use in the drying oil industry, the phosphatides and mucilaginous substances are removed by emulsifying the oil with hot water or steam, or sometimes with water containing a small percentage of alkali or alkali salts, and subjecting the emulsion to centrifuging to separate the so-called "break" material (168).

1. Neutralizing and washing

For production of an edible oil and for use in the production of certain products for the drying oil industry, soybean oil requires more drastic refining. This is usually effected by treatment of the oil with caustic soda. When first introduced into the United States, crude soybean oil from Manchuria was refined exactly as was cottonseed oil. The product was inferior and was not readily accepted by the food industry. About 1930 when domestic soybeans became available in considerable quantities, the methods used in refining corn oil were applied to soybean oil with marked improvement in the quality of the oil. Improvements in both equipment and the various operations of neutralization, washing, bleaching, winterizing, and deodorization followed rapidly with a constant improvement in the quality of the finished oil (58).

The neutralization of the crude soybean oil is effected by both batch and continuous methods (169, 130). In the former method the neutralization is carried out by means of treatment with alkali in large open-top cylindrical tanks called refining kettles, which are equipped with variable speed controlled agitators, heating coils or steam jacket, sprays for introducing the alkali solutions, and a jacketed settling cone. Refining kettles holding 20,000 pounds of oil are not uncommon. The oil, maintained at 20° to 25° C., is emulsified with 12 to 14° Bé caustic soda in slight excess above that required to neutralize the free fatty acids. Heating is carried out with moderate stirring until the so-called "break" appears. The break consists of small particles of soap derived from the free fatty acids originally present in the crude oil, excess caustic soda, unsaponifiable matter, and other impurities. With continued heating and slow stirring the small particles coalesce, and when a temperature of 65° to 70° C. is reached, they become fluid and tend to settle. Heating and stirring are discontinued at this point, and the soap stock is permitted to settle below the neutral oil. After settling in the refining kettle for 18 to 20 hours, the supernatant oil is drawn off. The neutralized oil is washed by stirring with 8 to 10 percent of water heated nearly to the boiling point, and again allowed to settle. After washing and drying, the oil is ready for bleaching or storage as may be desired. The soap stock is used for the production of free fatty acids or for various products of the detergent industry.

The batch process of neutralization has been superseded to a great extent by the continuous centrifugal method, especially in the United States where it is claimed that 80 to 90 percent of the oil is refined by the latter method. In this process crude oil is pumped to a feed tank equipped with an agitator to insure thorough mixing and to avoid the introduction of large quantities of settlings to the refining apparatus at any one time. Caustic soda solution of requisite strength is contained in a separate tank. Oil from the feed tank is withdrawn and passed through a proportionometer adjusted to deliver the proper ratio of oil to caustic soda. The oil and caustic soda, properly proportioned, leave the proportionometer by separate lines and are introduced into a high speed mixer. The resulting emulsion is forced through a tubular steam heater where the temperature is raised to 60° to 65° C. The time of contact between the oil and lye in the mixer is less than a minute and in the heater about 2 minutes, after which the oil and soap stock are continuously separated in a high speed centrifuge of the Sharples or DeLaval type. Figure 28 shows an installation of several such centrifuges.

The refined oil from the centrifuge contains less than 0.10 percent of soap and less than 0.20 percent of moisture, both of which must be removed by washing and drying in order to produce a stable oil of high quality. The refined oil from the centrifuge runs into a large receiving tank of 200 to 500 gallons capacity. The tank is equipped with steam coils and a temperature regulator to maintain the temperature of the contents at 70° to 80° C. as desired. As the neutral oil flows into the wash tank, hot water is continuously sprayed on its surface. The amount of water is maintained between 10 and 15 percent of the weight of the neutral oil. The wash tank which is either of the cone or dish-bottom type is provided with

an outlet at the bottom and a pipe line leading to a circulating pump of a capacity approximately three times as great as the net oil throughput. The pump circulates the hot oil and water mixture through a small elevated feed tank and back through an overflow line to the wash tank. The elevated feed tank is connected by a feed header to a battery of supercentrifuges. The feed line contains a float valve which opens only when the level in the wash tank has reached such a height that any unit volume of oil which enters it will remain in the system in contact with the water for approximately 10 minutes. Rapid circulation and mixing are maintained by the over-capacity pump, since two-thirds of the mixture of oil and water withdrawn from the bottom of the wash tank is always returned through the overflow, the balance being withdrawn through the float valve to the supercentrifuge.

The oil and water mixture is continuously separated in the supercentrifuge, and the separated water containing the soap is run to the sewer. The oil is generally washed a second time by the same process but at a higher temperature, usually 80° to 95° C. The discharged oil contains 0.4 to 0.5 percent moisture which must be removed as rapidly as possible to prevent hydrolysis of the glycerides and destruction of antioxidants during subsequent bleaching.

The removal of the moisture is effected by a process of continuous drying. The washed oil is run to a constant-level feed tank from which it is continuously fed in the form of a spray through a series of nozzles into the side of the vacuum chamber. A vacuum of about one inch is maintained in the chamber; for example, by means of a two-stage steam ejector and a barometric condenser. The oil spray is further broken up by a series of baffles to prevent entrainment, and the water vapor is exhausted by the ejectors. The washed and dried oil containing 0.002 percent soap and 0.05 percent moisture is continuously pumped from the drier and run to the bleach tanks or directly to storage as desired.

Several methods are under investigation, especially in the United States, which have for their objective the refining of soybean oil by means of activated adsorbents, the process being a continuous regenerative one. In common with all percolation processes, it possesses the following fundamental characteristics. The time of contact between the oil and the adsorbent is directly proportional to the depth of the bed and inversely proportional to the flow of oil through a bed of fixed cross section. The flow, in turn, is directly proportional to the cross sectional area of the column of adsorbent, and increases, although not in simple proportionality, with increasing pressure, increasing particle size, and decreasing depth of adsorbent. Decreasing particle size gives a more complete adsorption. Increasing temperature increases the flow by reducing the viscosity of the oil, but decreases the completeness of adsorption.

The Victor Chemical Works, Chicago, Illinois, have extensively investigated the adsorption refining of soybean oil by the use of activated tricalcium phosphate. Certain variables mentioned above have been fixed as a result of this work. For example, it has been determined that 5 times as much phosphatides are removed in the same column at 25° as can be removed at 65°.

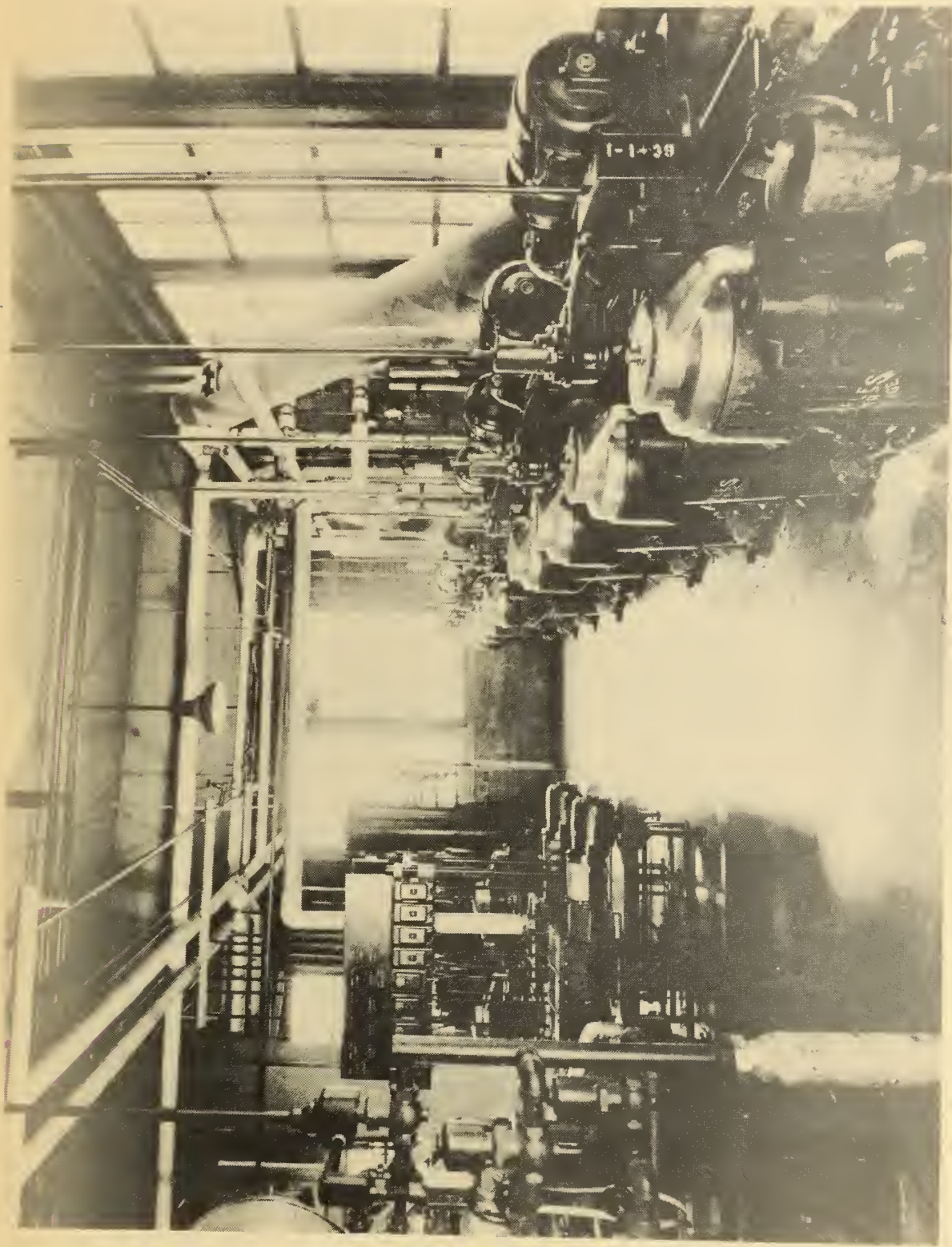


Figure 28.-- Battery of Sharples Super-Centrifuges, Soybean Oil Refinery, A. E. Staley Manufacturing Company, Decatur, Illinois. (Courtesy of H. A. LaMent, The Sharples Corporation, Philadelphia, Pennsylvania)

The optimum particle size of the adsorbent was found to be 20 to 30 mesh. Phosphatides and free fatty acids were found to be almost completely removed under optimum operating conditions, but the color was not greatly improved since tricalcium phosphate has a low adsorption capacity for carotenoid pigments. When hexane was used as a carrier solvent for the oil, no appreciable effect was observed in the removal of phosphatides, but the flow of oil was considerably increased. The spent adsorbent which holds approximately its own weight of oil and 10 percent of its weight of phosphatides can be regenerated by extraction with a series of four solvents. The adsorbent is first washed with acetone to remove the oil, then with benzol-methanol (90 to 10) to remove the phosphatides, one percent caustic soda in methanol to remove the fatty acids, and finally with methanol. The regenerated adsorbent is identical in behavior to freshly prepared material, and the loss in adsorbent is negligible. For continuous refining four towers are required.

The use of a "solid silicic-acid foam" for mechanically removing phosphatides, mucilages, sterols, pigments, etc., from crude oils has been proposed by Brewer and Fraybill (48). The adsorbent is produced by treating an aqueous sodium silicate solution with carbon dioxide to produce a rigid gel which is broken into small granules, treating the product with hydrochloric acid in water to liberate carbon dioxide within the mass, and then washing and drying the resulting "solid foam."

The high loss of oil resulting from conventional methods of alkali refining has led to the investigation of numerous other processes for removing the free acids and other impurities from crude glyceride oils. Although there appear to be no commercial installations at present, the method of extracting the impurities by means of solvents has attracted considerable interest. A liquid which is immiscible with the oil but in which the free fatty acids and other undesirable substances are soluble can be passed through a liquid-liquid extraction apparatus in counterflow to the oil in order to effect a continuous purification. Various patents have covered the use of amines (65, 123), furfural (74, 190), alcohols (30), and other substances for this purpose.

Another refining method, used to some extent in Europe, is the removal of free fatty acids and other volatile substances from the oil by vacuum steam distillation. The apparatus and procedure are not radically different from those described under deodorization, the essential operation being the passing of hot oil (200° to 280° C.) in thin films over baffles or other surfaces, under vacuum, flowing countercurrently to a stream of superheated steam.

2. Bleaching.

After the soybean oil is refined, washed, and dried, whether by the batch or continuous method, it is then bleached to remove most of the coloring matter (170). To accomplish this operation the washed and dried oil is run to a closed tank equipped for vacuum operation and fitted with a heating coil and agitator. Since soybean oil is somewhat difficult to bleach, a

mixture of acid-activated bleaching clay and activated carbon is added to the oil when the temperature reaches 75° to 80° C. Heating and agitation, either at atmospheric pressure or under vacuum, are continued until the temperature reaches approximately 110° C. and these conditions are maintained for an interval of 15 to 30 minutes. A siliceous filter aid may be added to assist in the filtration. At the end of the bleaching period the mixture is pumped through a filter press which retains the bleaching agent and adsorbed materials.

A number of the factors affecting the bleaching characteristics of soybean oil have been described by Robertson, Munsberg, and Gudheim (157). The possible advantages of employing a countercurrent system of multiple contact bleaching were pointed out by Hassler and Hagberg (95).

In plants handling large volumes of soybean oil the spent bleaching earth may be extracted to recover the oil which it retains (176). Because of its content of semi-drying oil, the spent bleaching material is a distinct fire hazard. The bleached oil from the presses is collected and further processed for use in the edible trade or used per se for certain non-edible purposes.

3. Hydrogenation

In general, the processing of crude soybean oil into finished oils consists of five steps, neutralization, washing, bleaching, hydrogenation, and deodorizing. The hydrogenation step is omitted in favor of winterizing in the production of salad oils, but when the finished oil is to be converted into shortening, margarine, or similar products, it is ordinarily hardened after being bleached. The process is carried out by bubbling hydrogen gas through the hot oil in the presence of a nickel catalyst, either in batches or by continuous operation, in order to saturate a substantial portion of the double bonds occurring in the fatty acid chains.

The complete hydrogenation process comprises a number of operations, the principal ones being:

1. Preparation of the catalyst.
2. Manufacture of the hydrogen.
3. Hydrogenation.
4. Catalyst recovery.

The methods for carrying out the steps in the process vary a great deal from one refinery to another, but the procedures for soybean oil are generally the same as those used on other edible oils. Since the general theory and technological applications of hydrogenation have been described in great detail in the literature (172, 66), the various steps in the hardening process will be mentioned only briefly.

Certain of the rare metals such as platinum and palladium are satisfactory hydrogenation catalysts, but practically all the commercial hardening which is carried out by batch methods is catalyzed by less expensive colloidal nickel.

The metallic catalyst can be prepared by either "wet" or "dry" methods, the former being the more commonly employed. In the wet method, a finely ground nickel salt such as nickel formate or nickel carbonate is added to the oil, and it is reduced to metallic nickel in colloidal form by passing a stream of hydrogen into the heated mixture. Since the temperature at which the reduction is carried out, approximately 460° F., is injurious to the oil, it is customary to prepare "catalyst concentrates" by filtering the reduced nickel, washing it with fresh oil, and re-suspending it in a small amount of fresh oil for addition to the large batches of oil in the hydrogenation converters. It is possible to reduce some mixed catalysts, such as 20 percent copper and 80 percent nickel, at lower temperatures so that the catalyst can be prepared directly in the oil to be hardened. The amount of catalyst required varies somewhat with the manner of preparation and the operating conditions, but it is generally between 0.1 and 0.5 percent of the weight of oil.

When the catalyst is prepared by the dry reduction method, an insoluble nickel salt is precipitated upon an inert carrier. For example, nickel carbonate can be precipitated upon fuller's earth by adding sodium carbonate to a suspension of the finely ground carrier in a solution of nickel sulphate. The product is washed, dried, and reduced by heating it in a stream of hydrogen. It is preferable to carry out the reduction at the lowest practicable temperature in order to obtain a very active catalyst, 550° to 650° F. being typical operating temperatures. The catalyst thus formed is added to the oil with care to prevent exposure to the air.

In batch hydrogenation, the oil is charged into tall steel tanks which vary a great deal in details of construction. They are equipped with heating coils and with a "spider" or similar device for spraying hydrogen into the bottom of the tank. The hydrogen gas, in most refineries, is generated either electrolytically or by reducing steam by means of iron. The hydrogenators, or converters, are also often equipped with a stirrer. Purified hydrogen is passed through the oil, and unabsorbed gas is withdrawn from the top, recompressed to the appropriate pressure, and again injected into the converter. A wide range of temperatures and pressures is employed, although 270° to 300° F. and 20 to 30 pounds per square inch might be considered typical operating conditions. The hydrogenation is continued until samples which are withdrawn exhibit the proper melting point or iodine number, approximately 100° F. and 60 to 70, respectively, in the cases where the ultimate product is shortening. The catalyst is filtered out of the hydrogenated product, and the residual nickel is reclaimed. The hardened oil is then deodorized, often after treatment with additional bleaching earth to bring about a final decolorizing.

Hydrogenation is also effected, to some extent, by continuous methods. In continuous installations, the catalyst chamber is a cylindrical cage in which there are packed nickel turnings or similar forms of nickel. The oil and hydrogen are pumped through the catalyst mass, under appropriate pressure and temperature conditions, and the hardening occurs while the oil is flowing through a series of these chambers. The spent catalyst is regenerated by anodic oxidation followed by reduction with hydrogen at a temperature of 250° C. The operation of continuous hydrogenation plants has been

described by Manderstam (129). The process is said to result in the formation of a higher proportion of isoöleic acid than is usually obtained in well regulated batch operations, and there is consequently less opportunity for its immediate introduction in this country.

The processes and derived products of hydrogenation of soybean oil have been the subject of numerous investigations, and a fairly voluminous literature has resulted therefrom. The effects of catalysts, temperature, and pressure have been principally investigated, especially with respect to the degree of hydrogenation and the type of products formed. Low pressures and moderate temperatures ordinarily have been employed for the production of semi-hardened products for use in the edible oil industry, and high pressure and temperatures for the production of more completely hydrogenated products for other uses. For production of shortening, it is desirable to obtain as low an iodine number as possible without hardening beyond the optimum consistency. Partial hydrogenation of linoleic acid, as an example, results in some products which are harder than others, i.e., isoöleic and oleic acids, respectively. It is advisable to employ a catalyst and conditions which are selective to the formation of oleic rather than isoöleic acid, since it is then possible to hydrogenate to a lower iodine value to obtain a given consistency or degree of hardness, and a more stable product results.

The selective or controlled hydrogenation of soybean oil at 180° C. in the presence of nickel was investigated by Hilditch and Moore (105) who found that the amount of saturated derivatives did not increase until the amount of linoleic acid fell to 10 percent or less. Similar results were found by Richardson, Knuth, and Milligan (152). Ueno and coworkers (193) investigated the nutritive value of soybean oil hydrogenated at 120° C. especially with respect to the effect on vitamin A activity. Mazume (134) investigated the formation of isoöleic acid during the low temperature hydrogenation of soybean oil and found that the greater the amount of catalyst used, the greater was the formation of isoöleic acid. The presence of a small amount of copper (0.3 percent) resulted in the formation of large amounts of isoöleic acid, whereas larger quantities (4.0 percent) gave only small amounts of the iso-acid. Exposure of the reduced nickel catalyst to air prior to use also resulted in increased production of isoöleic acid.

Gill and Ma (81) studied the effect of temperature, pressure, agitation, and amount of catalyst on the hydrogenation of soybean oil, and concluded that an increase in any one of these factors increased the rate of hydrogenation. However, at stirring rates of 320 r.p.m. and above, a temperature change of 10°, between the limits of 150° and 180° C., produced little or no effect on the rate of reaction. One percent of catalyst was found to be the maximum amount required for successful hydrogenation.

Waterman and Partram (201) investigated the hydrogenation of soybean oil with respect to the decrease in thiocyanogen and iodine numbers and found that the two characteristics differed widely in their respective rates of decrease. Waterman and van Vlodrop (203) investigated the hydrogenation of soybean oil with colloidal nickel catalyst prepared from nickel carbonyl and

obtained a product melting at 60° C. when the hydrogenation was carried out at a temperature of 60° C. and at atmospheric pressure for 1.75 hours.

Yamaguchi and coworkers (206) investigated the preparation of nickel and copper catalysts from the corresponding formates in the presence of soybean oil and the effect of time and temperature on the hydrogenation of the oil by those catalysts.

Botkovskaya (46) concluded from an investigation of the effect of the presence of phosphatides and peroxides on the hydrogenation of soybean oil that the former were without effect, whereas the latter were chiefly responsible for retarding the rate of reaction. Sato and Ozaki (166) claim that the use of a high-tension electric discharge increases the catalytic hydrogenation of soybean oil without affecting the quality of the reaction.

More recently considerable attention has been given to the effect of high temperatures and pressures on the course of the hydrogenation reaction of soybean oil. Waterman, van Lussenbroek, and van Dijk (202) investigated the hardening of soybean oil at pressures varying from 130 to 146 atmospheres at 32°, 50°, and 55° C. using 3 percent nickel-kieselguhr catalyst, and also at atmospheric pressure and a temperature of 175° to 180° C. Analysis of the hardened fats indicated that the formation of glycerides containing one or more saturated fatty acid residues was more pronounced in hardening at high pressures and low temperatures.

Shinozaki and Kubo (174) extensively investigated the high temperature and pressure hydrogenation of soybean oil, especially with respect to the formation of nonglyceride products. At temperatures below 250° C., hydrogenation with a copper-bearing catalyst resulted principally in the saturation of the various double bonds in the glyceride molecule, while between 300° and 325° C. considerable production of fatty acids occurred. The latter reaction reached a maximum at 350°, when alcohols began to be formed, and ceased abruptly at about 375° with the formation of hydrocarbons. Octadecyl stearate melting at 58.5° was isolated from the reaction mixture formed at 350°. When copper-chromium catalyst was employed at 390°, the wax ester formed at 325° to 350° was completely decomposed with the formation of higher hydrocarbons (octadecane), and between 410° to 450° gasoline-like oils of specific gravity 0.74 were formed in 70-percent yield. This last reaction was extensively studied by Shinozaki and coworkers (175) under various conditions. High pressures and a 60-minute reaction time resulted in a maximum yield of hydrocarbon oil. Temperatures below 430° C. were ineffective, and of the various catalysts examined, nickel salts gave the best results. With about 3 percent of this catalyst the oil which was obtained was colorless, had a specific gravity less than 0.7, and contained 1.1 percent unsaturated compounds, 7.6 percent naphthenic hydrocarbons, and 91.3 percent saturated compounds. Kino (116) investigated the production of ketones which were formed by heating hydrogenated soybean oils with magnesium powder at 300° to 350° C. The melting points of the resulting ketones were found to increase with the increase of saturated acids in the hardened oil.

Koyama (121) studied the high-pressure hydrogenation of soybean oil in the presence of a series of copper-bearing catalysts and concluded that a 70:30 copper-nickel mixture which was not pretreated with hydrogen was the most effective of the catalysts investigated.

The literature pertaining to the mechanism of hydrogenation reactions has been reviewed by McCutcheon (127).

4. Deodorization

Following the various treatments of neutralization, washing, bleaching, and hydrogenation, soybean oil still retains its characteristic taste and odor because of the presence of difficultly volatile substances. The removal of these substances is effected in the final step of the purification process. This deodorization is generally carried out by the batch method, although continuous deodorizers are used to a limited extent. In the batch method the oil is maintained at a temperature of 180° to 210° C. under a vacuum of 5 to 12 mm. for 6 to 8 hours or longer, during which time it is subjected to treatment with superheated steam.

Various designs of deodorizers are in use, and although differing somewhat in construction details, they consist essentially of a tank of 15,000 to 30,000 pounds capacity which is provided with an elaborate system of baffles to prevent carrying over of the oil with the steam; a multiple stage steam jet vacuum pump; steam compressor or other means of superheating the steam; a thermo-compressor to compress the vapors from the deodorizer; and a barometric condenser. The steam enters at the bottom of the column of oil 8 to 10 feet or more in height and passes upward and out through the condensing system. The proper temperature and flow of steam through the oil, as well as the length of time required to effect the maximum degree of deodorization commensurate with the production of the highest quality in the finished product, depend on the characteristics of the oil and on the skill and past experience of the operator. When, in the judgment of the operator, the oil has been properly deodorized, it is dropped to a vacuum tank equipped with cooling coils in which it is cooled before being further processed into edible products or before loading into tank cars, drums, or cans preparatory to shipment. Freshly deodorized soybean oil is bland, contains less than 0.02 percent fatty acids, and has a Lovibond color reading of 10 to 15 yellow and 1 to 1.5 red in a 123 mm. cell.

The disadvantages of the batch system of deodorization of soybean oil are the length of time which the oil must be heated, the poor contact between the oil and steam, and the hydrostatic pressure which increases from the surface to the bottom of the oil layer. Consequently, a number of continuous deodorization systems have been devised both in Europe (171) and in the United States which are intended to eliminate these disadvantages. The systems are all somewhat similar in principle and depend for their action on flowing a thin film of preheated oil downward over bubbling caps, plates, or a packing material, against a rising current of superheated steam. Deodorization of the oil is carried out in a high vacuum in 4 to 6 minutes, following

which the oil is rapidly cooled by being circulated through cooling coils. The Elliott Company, Pittsburgh, Pennsylvania, furnishes continuous deodorizing units in standard sizes ranging from 500 to 5,000 pounds per hour, and the Foster Wheeler Corporation, New York, New York, furnishes similar equipment (53, 54) capable of handling 24,000 to 144,000 pounds of oil daily. The Flaw-Knox Company of Pittsburgh, Pennsylvania, also offers a continuous deodorizing system.

5. Winterizing.

Winterizing is an operation which originated in the cottonseed oil industry. In order to obtain a salad oil which would remain clear in cool climates, the practice was adopted of allowing tanks of "summer" oil to stand out of doors during cold weather. The so-called "stearine" crystallized and settled out, leaving a supernatant "winter" oil suitable for use in the preparation of salad oils, mayonnaise, and similar products. The methods and equipment used in most of the large refineries have passed through several stages of development during evolution into their modern forms, although it is universally admitted that even present-day practice is extremely awkward in most respects. The development of winterizing technology has been described by Lee (126). Highly refined soybean oil will normally remain clear for an indefinite time when kept at 0° C., but most commercial oil will begin to freeze at -4° C. and remelt at about -3° C. The material which separates from refined soybean oil at low temperatures apparently does not consist of so-called stearines which are obtained from cottonseed oil under the same conditions. Earle and Detwiler (59) examined a wax obtained by solvent extracting the filter aid and precipitate remaining in the filter presses of a commercial soybean oil winterizing installation. They found the average chain length of the acids to be 22 carbon atoms, and the principal alcohols were found to have chain lengths of 28 to 32 carbon atoms. On the assumption that 50 pounds of filter aid are used for each 15,000 pounds of oil winterized, these authors concluded that the wax, containing about 10 percent of free alcohols, comprised 0.001 to 0.002 percent of the original oil.

It is important, in winterizing an oil, that the rate of cooling and circulation of the oil be controlled in a manner conducive to proper coalescence of the solid particles into easily filterable precipitates. The usual practice is to charge the oil into large horizontal tanks which are fitted with internal cooling coils. Although the usual heat transfer medium is brine which has been chilled by an ammonia refrigeration system, some of the recent installations perform the cooling by direct expansion of the refrigerant into the coils within the tanks. The oil is rather rapidly cooled to a temperature of 40° to 45° F., and it is allowed to stand for 2 or 3 days while the solid materials settle. The oil is then clarified by forcing it through precoated plate-and-frame filter presses which are installed in a refrigerated room.

The present methods for winterizing vegetable oils are thought by many to be unnecessarily time-consuming and to involve the tying up of excessive amounts of oil while the process is being completed. It is also quite

generally appreciated that a continuous winterizing method is hardly possible if carried out in a manner at all similar to the present practice, because of the length of time necessary for proper conditioning of the precipitate. However, analogous problems have been solved in the petroleum industry with the result that extremely large-scale dewaxing of lubricants is now quite commonly performed by continuous operations involving no appreciable hold-up of the product. The successful introduction of such methods into the vegetable oil industry would go a long way toward improving plant efficiencies and lowering processing costs.

6. Shortening

Usual types of shortening made from soybean oil are prepared by beating air or other gas into properly hydrogenated or hardened oil, the product being thoroughly emulsified. Such shortenings are made from pure soybean oil as well as from practically all other edible oils and from mixtures of various fats and oils. Approximately half of the soybean oil produced in this country is consumed in such products.

Ordinary vegetable oil shortening is made in either of two ways. The first method consists in hydrogenating an entire batch of oil until its iodine number is lowered to a given value, i.e., 60 to 70, or until it acquires the desired consistency at room temperatures. The sequence of operations is hydrogenation, deodorization, and solidification. Hydrogenation imparts a typical flavor which must be removed. The hardened material is then chilled, and air is whipped into it to produce the completed emulsion. Shortenings of this type are produced only in plants which have hydrogenation equipment, but they are generally considered to be the more stable type.

The other method of manufacturing comprises mixing unhardened oil with the proper amount of rather completely hydrogenated oil or oleostearine, the proportions being controlled to produce the desired degree of plasticity in the final product. The mixture is chilled and emulsified with air exactly as in the production of the completely hydrogenated type. Shortenings of this kind are made in many refineries which do not have hydrogenation equipment, since a relatively large amount of unhydrogenated oil can be sufficiently thickened by the addition of a small amount of completely hardened fat. The hardened components usually consist either of oleostearine or of fairly completely hydrogenated oil shipped to the refinery from some plant having hydrogenation facilities.

In either process, the methods of chilling the fat and emulsifying it are the same, although there are several methods of accomplishing the desired results. Until recent years, it was standard practice to run the hardened oil over a chill roll prior to the emulsification step. The roll is a horizontal steel cylinder about 9 feet long and 4 feet in diameter. It revolves at 6 to 10 revolutions per minute and is cooled to -10° to $+10^{\circ}$ F. by means of circulated brine or direct expansion of refrigerant. Liquid fat, at 120° to 130° F., is fed onto the roll and congeals in a thin, somewhat translucent film which adheres to the roll surface for nearly a complete revolution

before being removed by a scraper knife. Final temperature of the fat depends upon the roll temperature and upon the speed of rotation.

The chilled fat at a temperature of 50° to 70° F. falls into a trough, known as the "picker pan," in which it is beaten by pickers extending from a longitudinal shaft rotating at 80 to 180 revolutions per minute. The amount of air whipped into the mixture is governed by the speed and shape of the pickers and should be 8 to 12 percent by volume. Too much air results in a "fluffy" product, and insufficient beating causes a greasy or oily texture. The air introduced in the picker pan is finely subdivided and lumps are eliminated by forcing the mixture through screens, expansion valves, and other homogenizing devices at pressures usually approximating 400 to 600 pounds per square inch. The product is a white, creamy emulsion which rapidly crystallizes, setting to the firm consistency of lard or other shortening agents.

A more recent development in the production of shortening is the use of closed system chilling units, more often referred to as internal chilling machines. These are jacketed nickel or stainless steel cylinders, 6 to 8 inches in diameter and about 4 feet long, equipped with longitudinal scraper-stirrer blades. The blades are accurately mounted on a large-diameter mutator shaft which allows only about an inch of annular clearance between it and the cylinder wall. The scraper blades float in the cylinder and are made to bear lightly against its walls by centrifugal force and by the resistance of the fat to their rotation. The radial force thus developed is insufficient to cause metal-to-metal contact. Even microscopic films are scraped from the walls by the revolving blades, but no metal-to-metal contact occurs to afford opportunity for metallic contamination of the product. Cooling takes place by virtue of direct ammonia expansion in the jacket, and the liquid fat is forced through the cooling unit at a rate commensurate with the amount of cooling required. A separate inlet is provided for admitting air or inert gas to produce the emulsion. It has been variously claimed that the use of nitrogen, for example, in place of air results in a more stable shortening.

Internal chilling machines offer other advantages. The scraper action is so effective in rapidly removing congealed fat from the cold cylinder walls that much more efficient heat transfer occurs than can be obtained with the conventional chill roll. The consequently more rapid crystallization results in formation of finer crystals, improving the consistency of the product, and insures a relatively high capacity. Feed rate, gas influx, temperature, and pressure are more readily controlled, and it is therefore possible to make a more uniform shortening. Total enclosure of the process also prevents condensation of moisture in the fat during treatment.

The steps in the internal chilling process are approximately the same as those comprising the chill roll method. Hydrogenated oil, from storage, runs into a work tank having a float-operated level controller. A positive displacement pump withdraws oil from the work tank, and an inlet for air or inert gas is provided in the suction line. The mixture of gas and fat is forced through a pressure regulating valve into the chilling apparatus, or "A-unit," which usually consists of two cooling cylinders, Nos. 1 and 2,

although some makes use only one cylinder. The warm oil-gas mixture enters at the bottom of the vertical cylinder No. 1 and leaves from the top. It is then forced through cylinder No. 2 in a similar manner, and is discharged in a super-cooled condition. The effluent is then gently mixed in a horizontal cylindrical water-jacketed chamber, known as a "B-unit," while crystallization rapidly takes place with consequent evolution of heat. The entire system is under pressure up to this point, but the pressure is released when the crystallized product is extruded from the blending unit for packaging. The release in pressure causes expansion of the minute air bubbles and thereby results in a whiter color in the finished shortening.

7. Margarine

Margarine or oleomargarine is an emulsion of fats and oils, milk, and salt. The fat and oil comprise 80 to 85 percent and the salt 3 or 4 percent. During recent years, 16 to 20 percent of soybean oil consumption has been in the production of margarine. Soybean oil has composed 25 to 34 percent of the total quantity of fats and oils thus consumed, compared to 40 to 50 percent for cottonseed oil. The balance has consisted mainly of smaller amounts of coconut and oleo oils. Considerable quantities of margarine are made using only hydrogenated soybean oil as the fatty ingredients, but it is more generally the practice to blend hydrogenated soybean oil with other fats.

Production methods have been modernized during the past few years. In older processes, milk which has been soured to the proper acidity is mixed with the fat in a large churn having a cooling jacket. The milk is introduced first, at a definite temperature, and then the fat is added with vigorous stirring. The mixture is cooled and gradually becomes thicker in consistency and less transparent. Finally, crystallization takes place, causing an abrupt rise in temperature, but the churning is continued until the temperature commences to fall once more. The agitation is then discontinued, and the thick mass is discharged into a powerful stream of ice water. A trough or vat collects the water and crumbly margarine chunks, and the latter are skimmed off to be kneaded in a butter worker. Salt is added during the working process.

Modern plants employ a different congealing and emulsification technique. First, the milk is inoculated with a mother culture and allowed to ripen for 10 to 12 hours at 80° to 90° F., or until its acidity reaches approximately 10 percent. Glass lined or stainless steel closed tanks, with agitators and temperature control jackets, are used for this step of the process. Great care is taken in the preparation of the mother culture to prevent contamination, since the palatability of the finished product is dependent upon the specific action of the proper microorganisms in producing certain flavoring substances, mainly diacetyl. In the meanwhile, the fat or fat blend is prepared. If only one oil is used, having been previously hardened to the proper consistency, it is simply withdrawn from storage and pumped into the blending tank where its temperature is properly

adjusted. In other cases, a number of fats and oils are blended, the proper hardness of the blend being obtained by properly proportioning hardened and unhardened oils. A part of the milk, e.g., 25 percent, may be added to the fat in the blender with thorough stirring.

The fat is then withdrawn by a proportioning pump and forced at high pressure through ammonia-jacketed chilling tubes, or "A-units," similar to those used in the production of shortening. The balance of the milk, in which the proper amount of salt has been dissolved, is cooled to approximately 20° F. and pumped into the cold fat as it leaves the chilling tubes, and the mixture then passes through a blender. This is a horizontal tube with a central shaft having projecting mixing pins. The final setting to consistency required for forming and cutting takes place in the "P-unit" which is usually a series of three jacketed tubes. Screens between the tubes serve to break up any lumps, but there is no other mechanical stirring provided. Warm water is circulated through the jackets to keep material from sticking to the walls. In some cases, the chilling, crystallizing, working, and blending operations are all combined and carried out in a single chilling and agitating unit. In either case, the final product is extruded through a die in the form of a slab which is cut into proper sizes for packaging.

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